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Minimization and Control of Hazardous Combustion Byproducts

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This report describes the results of a research effort in which all relevant information regarding the minimization and control of hazardous combustion byproducts (Products of Incomplete Combustion, PICs) that result from operations in which hazardous waste is thermally destroyed (e.g., in incinerators, boilers and kilns) is summarized, analyzed and thoroughly described. The research was conducted cooperatively by the University of Dayton Research Institute (UDRI) and the EPA Risk Reduction Engineering Laboratory (RREL) under Cooperative Agreement CR813938-01-1. This report covers a period from February 1989 to February 1990.

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by

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FOREWORD

Today's rapid developing and changing technologies and industrial products and practices frequently carry with them the increased generation of materials that, if improperly dealt with, can threaten both public health and the environment. The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Risk Reduction Engineering Laboratory is responsible for planning, implementing, and managing research, development, and demonstration programs to provide an authoritative, defensible engineering basis in support of the policies, programs, and regulations of the EPA with respect to drinking water, wastewater, pesticides, toxic substances, solid and hazardous wastes, and Superfund-related activities. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

This report describes the results of a research effort in which all relevant information regarding the minimization and control of hazardous combustion byproducts (Products of Incomplete Combustion, PICs) that result from operations in which hazardous waste is thermally destroyed (e.g., in incinerators, boilers and kilns) is summarized, analyzed and thoroughly described. The research was conducted cooperatively by the University of Dayton Research Institute (UDRI) and the EPA Risk Reduction Engineering Laboratory (RREL) under Cooperative Agreement CR813938-01-1. This report covers a period from February 1989 to February 1990.

E. Timothy Oppelt, Director
Risk Reduction Engineering Laboratory

ABSTRACT

Control of emissions of toxic organic and organometallic compounds is one of the major technical and sociological issues surrounding the further implementation of incineration as a waste disposal alternative. A comprehensive review of the status of research concerning the emission of organic products of incomplete combustion (PICs) indicated that available full-scale data were insufficient in volume and quality to make firm conclusions. As enumerated below, several trends were identified which appeared to concur with scientific theory, and several deficiencies in fundamental knowledge and completeness of full-scale emissions data were observed.

PIC emissions are a natural consequence of the kinetically-limited thermal degradation of hazardous wastes. Comparison of PIC formation/destruction rates based on theory and nominal incineration conditions indicate that PIC emissions are always several orders of magnitude higher than predicted. This suggests that temporal or spatial excursions from these nominal conditions are occurring that are responsible for PIC emissions. Relative emission rates are controlled by failure conditions which arise in post-flame regimes of full-scale systems.

Consideration of waste feed composition and the reported emissions suggested that a significant fraction of PICs that may have been emitted from full-scale facilities were not analyzed. Analysis of PIC emissions data from 17 full-scale facilities further suggested that the magnitude of PIC emissions correlated with the completeness of the sampling and analysis procedures.

A comprehensive rank-order statistical analysis of full-scale emissions data indicated that of the design and operational parameters evaluated, stack oxygen concentration and waste heat load exhibited the strongest correlation with various measures of PIC emissions. Regulatory surrogates for PIC emissions (CO and TUHC) and stack benzene and toluene concentrations exhibited only occasional correlation with various measures of PIC emissions.

Analysis of specifically identified emissions indicated that simple halogenated methanes, halogenated ethanes, halogenated ethenes, and non-halogenated aromatic species were the most frequently observed and highest yield PICs. The high yields of the relatively fragile halogenated methanes and ethanes inferred that many of these PICs were formed downstream of the high-temperature zones of full-scale systems via radical-association reactions.

In conclusion, a series of design, operational, and regulatory implications for PIC control were presented. From the laboratory perspective, the urgent need for detailed studies of PIC characterization, yields, and emission mechanisms at elevated temperatures was emphasized. The benefits of interactions between laboratory-scale PIC studies, PIC toxicological studies, and sampling and analysis methods development for full-scale systems were also discussed.

This report was submitted in partial fulfillment of Cooperative Agreement CR813938-01-1 by the University of Dayton Research Institute under the predominant sponsorship of the U.S. Environmental Protection Agency. This report covers a period from February 1989 to February 1990.

CONTENTS

PAGE

Foreword....................iii
Abstract....................iv
Figures....................vii
Tables....................ix
Abbreviations and Symbols....................xii
Glossary of Terms....................xiv
Acknowledgment....................xviii

1. Introduction....................1
2. A Theory of PIC Formation....................10
    Mechanism 1: Concerted Unimolecular Elimination Reactions....................10
    Mechanism 2: Complex Radical-Molecule Pathways....................15
        Bond Fission....................16
        Hydroxyl Radical Attack....................18
        Hydrogen Atom Attack....................23
        Chlorine Atom Attack....................26
        Molecular Growth Reactions....................29
    Mechanism 3: Radical-Radical and Radical-Molecule Association Reactions....................49
    Literature Summary of PIC Formation Studies....................60

3. Pilot- and Full-Scale Emissions Analysis....................78
    Background on Source Tests and Facilities....................79
    Full-Scale Emissions Analyses....................90
    Pilot-Scale Emissions Analyses....................106
    Summary....................119

4. Discussion....................122
    Full-Scale Hazardous Waste Incinerators....................136
    Pilot-Scale Hazardous Waste Incinerators....................142
    Full-Scale Boilers....................147
    Full-Scale Co-Fired Kilns....................147
    General Observations and Conclusions....................152

5. Implications for PIC Control (Suggested Areas for Further Research)....................155
    Design Implications....................156
    Operation Implications....................160
    Regulatory Implications....................161

References....................163
Appendices....................171

APPENDICES

A - Full-Scale Hazardous Waste Incinerator Emission Sources 171

B - Full-Scale Industrial Boiler Emission Sources. 204

C - Full-Scale Cement Kiln Emission Sources. 227

D - Pilot-Scale Hazardous Waste Incinerator Emission Sources 238

E - Part I. Emissions Analysis---Full-Scale Hazardous Waste Incinerators 263

F - Part II. Emissions Analysis---Full-Scale Hazardous Waste Incinerators 282

G - Part I. Emissions Analysis---Full-Scale Industrial Boilers 298

H - Part II. Emissions Analysis---Full-Scale Industrial Boilers 309

I - Emissions Analysis---Full-Scale Cement Kilns 319

J - Part I. Emissions Analysis---Pilot-Scale Hazardous Waste Incinerators 329

K - Part II. Emissions Analysis---Pilot-Scale Hazardous Waste Incinerators 359

L - Part III. Emissions Analysis---Pilot-Scale Hazardous Waste Incinerators 369

FIGURES

NUMBER		PAGE
1.1	Thermal decomposition profile for kepone in flowing air	3
1.2	Fuel-lean combustion of trichloroethylene (C_2HCl_3) illustrating the stability of PICs versus POHCs	4
1.3	Representative gas chromatographic-total ion current (GC-TIC) chromatogram of the acid fraction extraction of a MM-5 train for semi-volatile organics	6
2.1	PIC formation zones in a hazardous waste incinerator	11
2.2	PCB degradation and PCDF formation/destruction profiles	22
2.3	Soot yields versus temperature in the pyrolysis of chlorinated methanes at a reaction time of 1.0 ms	30
2.4	$CHCl_3$, C_2Cl_4, and C_2HCl_3 mole fractions versus distance above the burner surface at a constant ϕ of 0.80	30
2.5	Comparison of the experimental data with model predictions for C_2Cl_6, and C_4Cl_6, and the experimentally derived C_6Cl_8 profile	32
2.6	Atmospheric pressure oxidative pyrolysis of CH_3Cl in helium	36
2.7	Product distributions from the atmospheric pressure oxidative pyrolysis of CH_2Cl_2 in helium	36
2.8	Product distributions from the atmospheric pressure oxidative pyrolysis of $CHCl_3$ in helium	37
2.9	Product distributions from the atmospheric pressure oxidative pyrolysis of CCl_4 in helium	37
2.10	Product distributions from the atmospheric pressure pyrolysis of C_2Cl_4 in helium	42
2.11	Plausible C_4Cl_6 formation pathways	42
2.12	Scheme for the formation of C_4Cl_6 (or C_4H_6) from C_2Cl_3 (or C_2H_3) and C_2Cl_4 (or C_2H_4) - Only the CHC reaction is shown	44
2.13	QRRK calculation for the C_2Cl_3 + C_2Cl_4 and analogous hydrocarbon reaction	45

2.14 Chemically activated chlorine displacement and isomerization reaction channels to formation of hexachlorobenzene and octachlorostyrene 46

2.15 Chemically activated chlorine displacement and isomerization reaction channels to formation of octachloronaphthalene and octachloroacenaphthylene 47

3.1 Average relative magnitudes of %PIC and %CLPIC emissions from full-scale incinerators 95

3.2 Average relative magnitudes of %PIC and %CLPIC emissions from full-scale boilers and kilns 96

3.3 Average relative magnitudes of %PIC emissions from full-scale boilers. 99

5.1 Hypothetical residence time distributions. 157

5.2 Schematic of hazardous waste incinerator temperature profiles 159

TABLES

NUMBER PAGE

2.1 Description of Hazardous Wsate Incinerator PIC Formation Zones and Dominant PIC Formation Mechanisms. . 12

2.2 Some Experimentally Documented Unimolecular Elimination PIC Formation Pathways 14

2.3 Bond Dissociation Energies for Some Organic Molecules. . 17

2.4 Arrhenius Parameters for Bond Fission Reactions. 19

2.5 Summary of Experimental Rate Data for H Abstraction by OH 24

2.6 Summary of Experimental Rate Data for H (and Cl) Abstraction by H 25

2.7 Summary of Experimental Rate Data for Displacement by H. 27

2.8 Summary of Experimental Rate Data for H Abstraction by Cl 28

2.9 Chemical Kinetic Mechanism for the Combustion of C_2HCl_3. 33

2.10 Chlorinated Methane Decomposition Rate Parameters . . . 38

2.11 Low Temperature (<800°C), Oxygen-Free, $CHCl_3$ Elementary Kinetic Mechanism 40

2.12 Arrhenius Parameters for Some Association Reactions Involving Radicals 51

2.13 Thermodynamic Properties of Selected Radicals Produced in Hazardous Waste Incineration 52

2.14 Some O-H, C-H, and C-C Single Bond Strengths in Radicals 55

2.15 Rate Expressions for the Decomposition of Some Common Radicals 57

2.16 Reaction Rate Parameters for Cool Zone Reactions of Radicals and O_2. 59

2.17 Summary of Reaction Products Observed from Thermal Decomposition of Various Materials in UDRI Flow Reactor. 61

2.18 Thermal Reaction Products Observed from the Thermal Decomposition of HWM-1 67

2.19 Summary of Reaction Products Observed from Literature Thermal Decomposition Studies. 70

3.1 Distribution of Incinerator Types and Control Devices. . 80

3.2 Range of Combustion Parameters - Incinerators 80

3.3 Comparison of External Quality Assurance Relative Error Results for Volatile Organic Compounds 82

3.4 Comparison of External Quality Assurance Relative Error Results for Semivolatile Organic Compounds 83

3.5 Compilation of all Target Compounds from Dow Incinerator Study 84

3.6 Range of Combustion Parameters - Boilers 86

3.7 Target Compounds for Site D,E,F, and G Boiler Studies and Their Detection Limits 88

3.8 Target Compounds for Site I and Site II Kiln Studies and Their Detection Limits 91

3.9 % PIC Emissions - Incinerator Tests 93

3.10 % PIC Emissions - Boilers Tests 94

3.11 % PIC Emissions - Kiln Tests 94

3.12 % PIC Emissions Per Fuel/Waste Input - Boiler Tests. . . 99

3.13 % PIC Emissions Per Fuel/Waste Input - Kiln Tests . . . 99

3.14 Specific PIC Emissions - Incinerator Tests 101

3.15 Specific PIC Emissions - Boiler Tests 104

3.16 Specific PIC Emissions - Kiln Tests 105

3.17 Range of Combustion Parameters---Pilot-Scale Studies . . 107

3.18 Effect of Kiln Temperature on PIC Emissions - Chlorinated Benzene Study 108

3.19 Effect of Temperature and Oxygen Concentration on PIC Emissions - 5 Component Synthetic Mixture Study 110

3.20 % PIC Emissions---Pilot-Scale Afterburner Sampling . . . 111

3.21 % PIC Emissions---Pilot-Scale Stack Sampling. 112

3.22 Specific PIC Emissions---Pilot-Scale Afterburner Sampling 114

3.23 Specific PIC Emissions---Pilot-Scale Stack Sampling . . 115

4.1 Quantities Characteristic of PIC Emissions Used as Dependent Variables in the Statistical Analysis 123

4.2 Quantities Characteristic of PIC Emissions Used as Independent Variables in the Statistical Analysis . . . 124

4.3 Statistical Analysis of PIC Data from the Dow Hazardous Waste Incinerator 126

4.4 Statistical Analysis of PIC Data from the American Cyanamid Hazardous Waste Incinerator 127

4.5 Statistical Analysis of PIC Data from the Zapata Hazardous Waste Incinerator 128

4.6 Statistical Analysis of PIC Data from the TWI Hazardous Waste Incinerator Under Optimal and Failure Mode Conditions 129

4.7 Statistical Analysis of PIC Data from the IRF Pilot Facility During SF6 Testing 130

4.8 Statistical Analysis of PIC Data from the IRF Pilot-Scale Facility During Testing of 1,2,4-Trichlorobenzene and Hexachlorobenzene 131

4.9 Statistical Analysis of PIC Data from Acurex Boiler Study Site D 132

4.10 Statistical Analysis of PIC Data from Acurex Boiler Study Site E 133

4.11 Statistical Analysis of PIC Data from Acurex Boiler Study Site F 134

4.12 Statistical Analysis of PIC Data from Acurex Kiln Study Site 2 135

4.13 Summary of Statistical Correlation Results for Full-Scale Hazardous Waste Incinerators 137

4.14 Summary of Statistical Correlation Results for Pilot-Scale Hazardous Waste Incinerators 143

4.15 Summary of Statistical Correlation Results for Boilers Co-fired with Hazardous Wastes 148

LIST OF ABBREVIATIONS AND SYMBOLS

DRE	--Destruction and Removal Efficiency
DE	--Destruction Efficiency
APCD	--Air Pollution Control Device
kcal	--kilocalorie
L	--liter
mol	--mole
s	--second
°F	--degree Fahrenheit
°C	--degree Celsius
°K	--degree Kelvin (absolute)
$S^\circ{}_T$	--denotes absolute entropy of the thermodynamic standard state at the absolute temperature T
$\Delta H^\circ_{f,T}$	--denotes standard enthalpy of formation, which is increment in enthalpy associated with the reaction of forming the given compound from its elements, with each substance in its thermodynamic standard state at the given temperature
$\Delta G^\circ_{f,T}$	--denotes standard Gibbs energy of formation, which is increment in Gibbs energy associated with the reaction of forming the given compound from its elements, with each substance in its thermodynamic standard state at the given temperature
$\Delta H^\circ_{R,T}$	--denotes enthalpy change in a given reaction at a given temperature at constant pressure with all reactants and products in their appropriate states
$\Delta G^\circ_{R,T}$	--denotes Gibbs energy change in a given reaction at a given temperature at constant pressure with all reactants and products in their appropriate states
$T_{99}(2)$,(°C)	--denotes temperature (°C) for 99% decomposition of a specific compound for a mean, gas-phase residence time of 2.0s
t_b	--breakthrough residence time
μ , u	--micron (10^{-6})

A --Arrhenius pre-exponential factor

n --temperature exponent of the modified Arrhenius equation

E_a --Arrhenius activation energy

σ --collision diameter associated with Lennard-Jones collision rate

ϵ --well-depth associated with Lennard-Jones collision rate

β --collision efficiency

$-(\Delta E)$ --average energy transferred per collision

Eqn --Equation

R__ --Reaction (number)

Rxn --Reaction

Φ --Equivalence Ratio

GLOSSARY OF TERMS

Abstraction: A bimolecular reaction where an atom (or radical) is abstracted from a reactant by a radical species; same as metathesis; e.g., H abstraction: $CH_3Cl + OH \dashrightarrow CH_2Cl + HOH$.

Appendix VIII Thermal Stability-Based Incinerability Ranking: Listing of relative POHC incinerability; incinerability for a given compound determined by experimental and theoretical evaluation of thermal stability index (temperature for 99% destruction for gas-phase residence time exposure of 2.0s).

Arrhenius Parameters: Parameters which describe rate coefficients and their dependencies on temperature and pressure.

Bimolecular Reactions: Chemical transformation where two species collide and change chemical identity; function of temperature, pressure, reaction atmosphere, and concentration of reacting species.

Bond Fission: A unimolecular reaction involving cleavage of a chemical bond (typically the lowest energy bond in a molecule) between two atoms, a radical and an atom, or two radicals.

Bond Homolysis: Same as bond fission.

Bond Rupture: Same as bond fission.

Chlorinated Aromatic: An aromatic compound containing a Cl atom(s) substituent; e.g. chlorobenzene (C_6H_5Cl).

Chlorinated Ethylene: A C_2-alkene containing a Cl atom(s) substituent; e.g., chloroethylene (C_2H_3Cl).

Chloro-Olefins: Same as chlorinated ethenes.

Chromatographic Analysis: Analytical separation of organic compounds in complex mixtures, in this case by programmed temperature gas chromatography.

Concerted Molecular Elimination: A unimolecular reaction involving the elimination of a stable molecule from the reactant via a three-, four, or six-center transition state.

Displacement: A bimolecular reaction where an atom or radical is exchanged from one reactant to the other during the process.

Data Precision: Measure of how exactly the result is determined, without reference to what the result means; measure of reproducibility of result; in text, quoted as relative precision, i.e., uncertainty in terms of a fraction of the value of the result.

Day-to-Day Uncertainty: Precision of result, quoted in text as relative precision, taken on different days.

Elemental Composition: Atomic composition of mixture of compounds broken down to smallest integer values for specific atoms; e.g., 39.5 mole % CH_2Cl_2, 15.5 mole % C_2H_3N, and 45.0 mole % C_7H_7Cl is approximately equal to $C_3H_3Cl_1N_1$.

Equilibrium: Moment in time when, for a given elementary reaction, the forward and reverse reactions are proceeding at the same rate; defined by the equilibrium constant, K.

Excess Air: A larger quantity of air than required for stoichiometric oxidation or combustion; is equal to % theoretical air minus 100.

Failure Mode: An excursion from normal operating conditions which controls incineration efficiency.

Flame Zone: Three-dimensional space in incinerators where emission of visible light is accompanied by large exothermic chemical reaction, radical concentrations, temperature gradient, and rapid reaction rate.

Fuel/Oxygen Stoichiometry: Quotient of [ratio of moles (or mass) of fuel divided by moles of oxygen] of actual experiment divided by [ratio of moles of fuel divided by moles of oxygen] for stoichiometric oxidation.

Gas-Phase Thermal Decomposition Kinetics: Generic term applied to high-temperature thermal decomposition (oxygen concentrations less than the stoichiometric value) in absence of significant exothermic chemical reactions, super-equilibrium radical concentrations, and temperature gradients.

Haloethanes: Halogenated ethanes; e.g., trichlorotrifluoroethane.

Halomethanes: Halogenated methanes; e.g., trichlorofluoromethane.

Hierarchy: A body of data organized according to rank.

Inorganic: A molecule not characteristic of an organic compound, namely one generally not of animal or plant origin; a less general definition is a molecule which does not contain carbon.and hydrogen.

Isomer: Chemical substances with same number of characteristic atoms which are electronically arranged differently producing compounds with distinguishable physical and chemical properties; e.g., the atoms in dichloroethane ($C_2H_4Cl_2$) can be arranged as 1,1-dichloroethane (CH_3CHCl_2) or 1,2-dichloroethane (CH_2ClCH_2Cl).

Post-Flame Zone: Three-dimensional space in incinerators where high-temperature oxidation occurs in absence of emission of visible radiation and large exothermic chemical reactions; temperature gradients, radical concentrations, and reaction rates are substantially lower than flame zone.

Pyrolytic Thermal Decomposition: Thermal decomposition of an organic compound in the complete absence of oxygen.

Radical: Molecule or atom with at least one unpaired electron.

Radical Attack: Generally a bimolecular reaction between a stable molecule and a radical species, e.g., H atom metathesis or Cl atom displacement.

Rate Coefficient: Parameter which relates reaction rate of a given molecule(s) to its concentration(s).

Residence Time: Defined as mean, gas-phase time at reactor temperature; usually directly proportional to mass flow rate.

STANJAN Equilibrium Code: Computer program developed at Stanford University which enables one to quickly calculate the equilibrium high-temperature (or pressure) composition of an organic mixture (e.g., fuel + oxidant) with input of the thermochemical properties of the predicted high-temperature composition.

Thermal Decomposition Curve: Describes thermal behavior of a given sample or mixture; usually plotted as mass fraction (initial amount determined by a series of quantitation experiments at temperature where no chemical reaction occurs) on logarithmic scale versus exposure temperature (independent variable).

Thermochemical Transition State Theory: Reaction kinetic theory developed largely by S. W. Benson and co-workers where rate coefficients for chemical transformation are estimated by considering the changes in thermodynamic quantities (changes in enthalpy and entropy) as one travels from initial reactants to the transition state; assumes the nature of the transition state determines the extent of reaction.

Unimolecular Pathway: Chemical transformation of molecule which is function of temperature, pressure, and concentration and is independent of reaction atmosphere.

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SECTION 1

INTRODUCTION

Of all the issues surrounding disposal of toxic wastes, the potential for the formation and emission of so-called "Products of Incomplete Combustion" (PICs) from the thermal disposal of toxic wastes is the most controversial.[1-4] The currently permitted processes that encompass thermal disposal of toxic wastes, i.e., incineration, co-firing in boilers, co-firing in industrial kilns, are themselves controversial due to their unfortunate public perception as "landfills in the sky." This misconception is at least in part due to the lack of knowledge on PIC control.

Current regulations address particulate control, control of hydrochloric acid (HCl), and destruction and removal efficiency (DRE) of so-called Principal Organic Hazardous Constituents (POHCs) within a waste.[5] Selection and demonstration of the required 99.99% DRE for POHCs has also been controversial due to the permitting procedures that require the selection and demonstration of destruction of only a few surrogate POHCs that are considered environmentally significant and difficult to destroy.[6,7] This procedure has led to considerable research concerning the development of an incinerability index to aid selection of stable POHCs for trial burn testing.[8] Although, the scientific basis for construction of an incinerability index has been a source of continuing debate, it has received its most harsh criticism due to its lack of applicability to PIC control.[2,9] It was originally hoped that destruction of the most stable POHCs would assure equal or greater destruction of the most stable PICs. Lack of scientific proof of this idea has led to continued doubt as to the effectiveness of the current outlook for PIC control.

There has been a continuing debate over the regulatory meaning or definition of the term PIC; however, the practical definition should be clear. From an environmental perspective, we are concerned with the emissions of toxic organic compounds formed from the partial thermal degradation of the waste within the incineration process. Any reaction product other than thermodynamic endproducts should be considered a PIC. This includes reactions within the flame, post-flame and air pollution control regions of the facility. It is PICs included in this definition that we address in this report.

As a result of research performed primarily under sponsorship of the US-Environmental Protection Agency (US-EPA) in the 1980's, a partial scientific framework for considering the source of PICs has arisen. Although there is still and will continue to be some debate, often heated, concerning these findings, there are a certain number of points for which the responsible scientific and engineering community have reached a consensus. These "accepted" theories form a basis from which we can explore the more controversial aspect of the environmental impact of PIC emissions.

A seemingly trivial, yet amazingly controversial point is that PICs are a natural consequence of the thermal degradation of organic compounds. Although decades of chemical kinetic research and more recent laboratory studies of the thermal degradation of toxic organic compounds have demonstrated the formation of PICs, limited full-scale emissions data have led some individuals to question their actual existence.[2,9]

The simple scientific truth is that PICs will, in the vast majority of cases, tend to persist after the parent POHCs have been destroyed. This is graphically demonstrated in Figures 1.1 and 1.2. In fact, the environmental controversy over emissions of PICs is often attributed to the laboratory observation of three PICs (hexachlorocyclopentadiene, hexachloroindenone, and hexachlorobenzene) from the thermal decomposition of the pesticide kepone.[10] PICs are not always intrinsically more stable than the parent POHC; however, their final concentration may be higher because they are formed downstream in the combustor and experience a shorter residence time in the high temperature regions of the combustor. The observation that the parent kepone was destroyed at temperatures <500°C for a 1.0 s gas-phase residence time, while observed PICs required greater temperatures for destruction, has caused considerable concern. Subsequent laboratory studies, which showed that very toxic polychlorinated dibenzo-p-dioxins

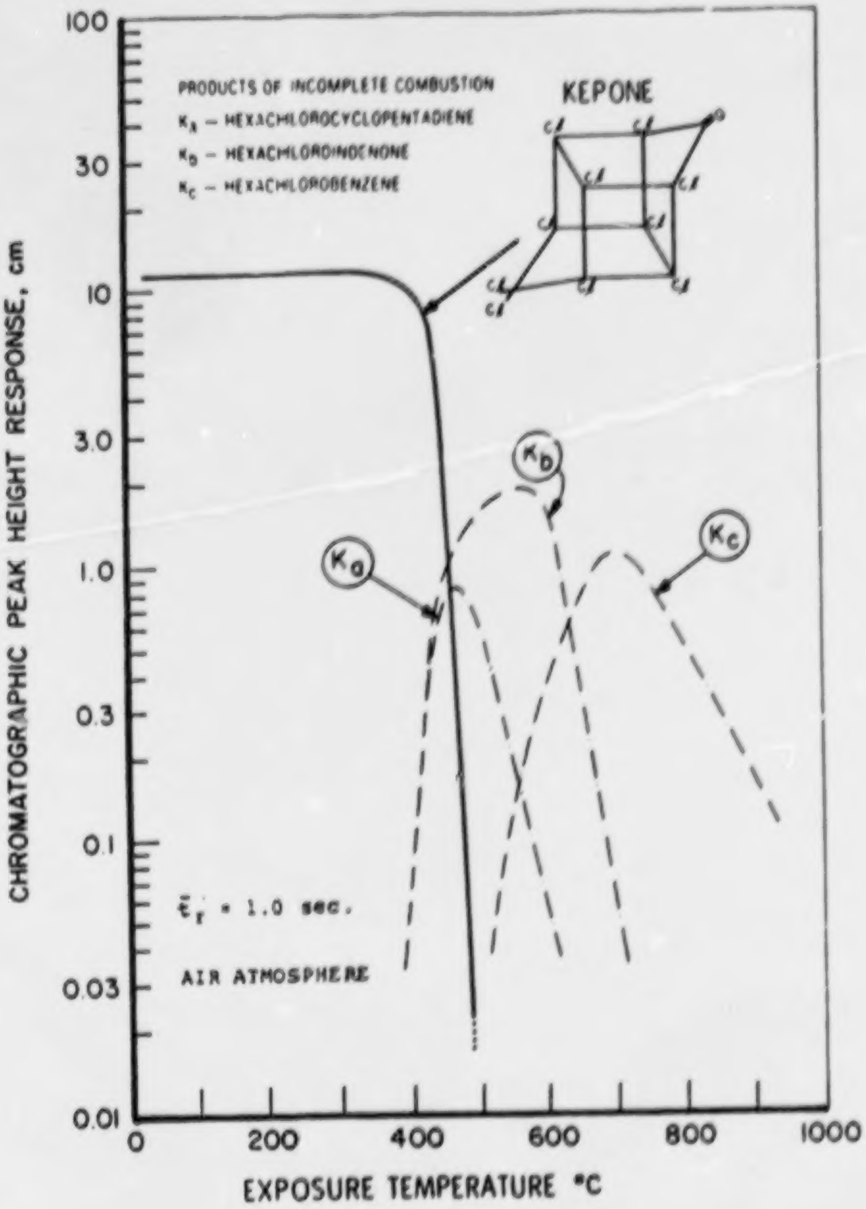


Figure 1.1. Thermal decomposition profile for kepone in flowing air[10].

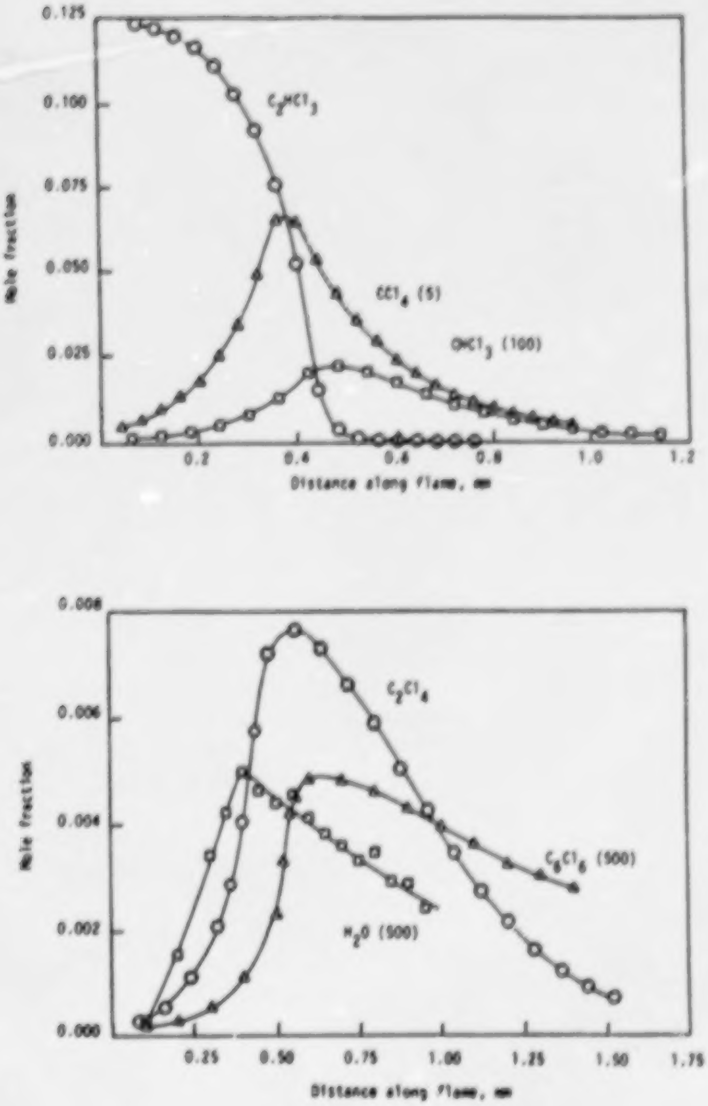


Figure 1.2. Fuel-lean combustion of trichloroethylene (C_2HCl_3) illustrating the stability of PICs versus POHCs.[11]

(PCDDs) could be formed from condensed phase thermolysis of chlorobenzenes (ClBz) and chlorophenols (ClP),[12,13] and observation of formation of polychlorinated dibenzofurans (PCDFs) from the gas phase thermal degradation of polychlorinated biphenyls (PCBs),[14,15] further served to heighten concern over PIC emissions. Numerous other laboratory studies of PIC formation have been performed in the past 10 years.[16]

As full-scale incinerator testing began, emphasis was placed on determining DRE of selected POHCs within the waste because only these compounds were the target of EPA regulation.[16,17] PICs were not regulated because of the difficulty in writing a scientifically defensible, enforceable regulation. However, as public and scientific concern grew, these same full-scale test data were reexamined for possible PIC formation. Of course, since the testing was not originally designed to observe PICs, the emissions data base was incomplete due to a variety of sampling and analytical problems and uncertainties well known to the practitioner.[18]

Figure 1.3 presents a typical chromatogram of the analysis of the acid fraction of a MM-5 train for semivolatile organics.[3] This figure graphically illustrates the difficulty in arriving at firm conclusions concerning PIC emissions from full-scale test data. Since each peak represents a PIC or residual POHC for one small fraction of the stack effluent, it is evident that a multitude of compounds are emitted. Identification of specific compounds within this morass has led to specific analysis for small lists of possible PICs, resulting in other emissions never being reported. Thus, it appears that a simple waste feed is partitioned by thermal degradation into a countless number of PICs which are essentially unquantifiable. Recent attempts to fully characterize organic effluents from full-scale test burns has produced limited success, i.e., 30-70% of the uncombusted material on a mass basis was identified, thus demonstrating the difficulty and the lack of completeness of PIC characterization.[17-19]

The initial conclusion to this discussion is that our basic understanding of combustion chemistry clearly indicates PICs will be formed and their total concentration will usually be greater than the concentration of residual POHCs. Although field data is inconclusive due to our limited

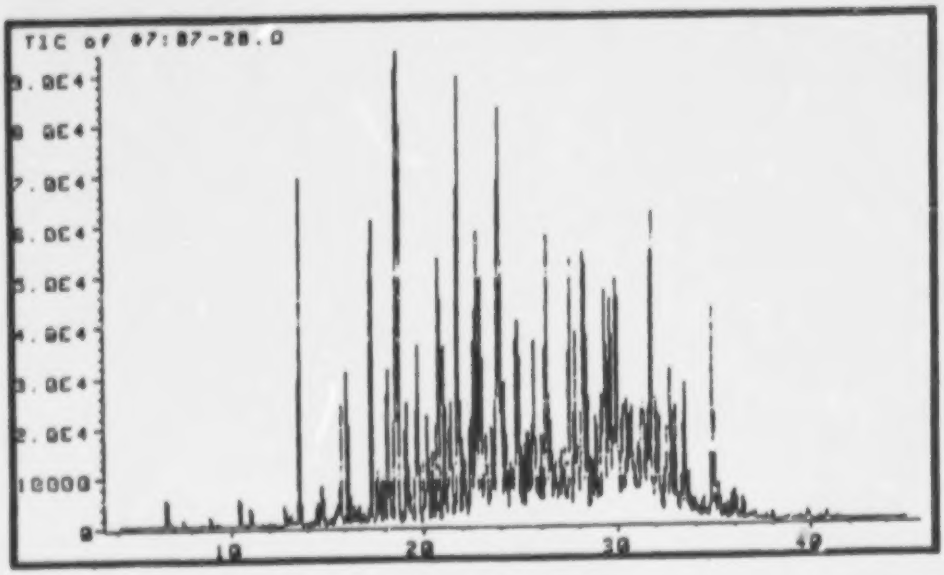


Figure 1.3. Representative gas chromatographic-total ion current (GC-TIC) chromatogram of the acid fraction extraction of a MM-5 train for semi-volatile organics.[3]

ability to sample and analyze for PICs, the real issues are which toxic PICs are formed, how they are formed, and how they may be controlled.

A second consensus theory is that PICs are kinetically, not thermodynamically controlled. This finding has arisen from numerous thermodynamic equilibrium calculations that consistently demonstrate that predicted levels of PICs as well as residual, undestroyed POHCs in the waste stream, are at least 10 orders of magnitude greater than that predicted assuming the incinerator achieves thermodynamic equilibrium[20-22]. Although this result is perfectly reasonable, it has caused much confusion and concern. It does not imply that PIC emissions are only affected by chemical reaction kinetics, and not other "physical kinetics" such as waste feed rate, rate of waste vaporization, rate and extent of waste/air mixing. It is only meant to imply that PIC emissions cannot be estimated from a thermodynamic equilibrium calculation using nominal process conditions with the assumption that the incinerator is a "gigantic calorimeter." Instead it may be more properly viewed as a non-premixed "flame and flow reactor."

A third generally accepted theory is that incineration appears to be capable of destroying POHCs and PICs to environmentally acceptable levels if operated under optimum conditions. For example, numerous flow-reactor studies have shown that under oxidizing conditions, a gas phase residence time of 2.0 s and a temperature of 1000°C (~1800°F) appears to be sufficient to destroy any known toxic organic compound with >99.9999% destruction efficiency (DE) and result in PICs with yields of <0.0001%.[16] Although it is certainly arguable whether these levels of destruction are sufficient to protect the environment, they do appear to be scientifically reasonable values from which to base a rational discussion of control of PIC emissions. Regardless of the source of the kinetic data, i.e., pre-mixed flame, flow reactor, or elementary reaction studies, the results consistently indicate that nominal conditions in a modern, controlled incinerator are sufficient to convert essentially all organic compunds to thermodynamically, stable combustion endproducts (CO_2, H_2O, HCl, etc.).[23]

Measurable emissions of organic compounds from full-scale test burns suggest, however, that nominal incinerator conditions are not actually achieved.[17] These excursions from nominal values have been dubbed failure modes and may be design or operational, spatial or temporal, and continuous or transient in nature.[24] This concept has already been discussed in publications and reports concerning the development of an index of toxic organic waste incinerability.[8,25] It has been argued that spatial and temporal fluctuations in the degree of waste/air mixing are principally responsible for less than optimal destruction of POHCs, i.e., pyrolysis pockets where waste destruction is slowed versus oxidation is responsible for most of the observed emissions of undestroyed POHCs.[26-28] These fluctuations may be spatial due to poor placement of burners or air inlets or temporal due to flash vaporization of an overload of solid or liquid waste feed. Secondary, but still significant failure modes are thermal quenching due to flame instability, too much secondary air, or too cool boiler walls. Residence time failures (distributions) due to non-plug flow conditions (plug flow is almost always assumed in residence time calculations) may also reduce waste destruction. Thus, one must consider the full-range of operating conditions of an incinerator when addressing PIC emissions, not just the normally quoted nominal conditions which are, at best, inconsistently reported.

With these relatively well accepted conclusions as a basis, we have undertaken the task of compiling a volume of currently available information concerning PIC emissions from hazardous waste incinerators, co-fired boilers, and co-fired industrial kilns. In Section 2, we review and compile fundamental and applied laboratory reaction kinetic data on PICs. In Section 3 we present the results of an analysis of pilot and full-scale data in relation to the mechanisms and theory developed in Section 2. Section 4 describes an attempt to statistically correlate design and operating parameters in an effort to determine which parameters most significantly affect PIC emissions. We conclude this section with a discussion of conclusions that can be drawn from the analysis of laboratory, pilot, and full-scale results. Section 5 presents a list of suggested areas for further investigation for minimization and control of PICs.

In the preparation of this report, we have attempted to address certain issues which the reader should keep in mind when reviewing the contents of this document. They are:

1. Are there identifiable rules by which the types, yields, and stabilities of PICs can be predicted?
2. Is there a procedure by which theoretical and laboratory analysis can be applied to field test results?
3. What is the quality and completeness of field data and how can this data best be used in spite of its apparent limitations?
4. Which design and operational parameters most significantly affect PIC formation and destruction?
5. What process, operation, or regulatory strategies are available to control and minimize PIC emissions?

SECTION 2

A THEORY OF PIC FORMATION

There are many ways to categorize reactions that lead to the formation of stable products. From an incineration viewpoint, it might be most useful to classify reaction pathways in a manner that they can be associated with regions of the incinerator where they are the most significant. Figure 2.1 shows a typical rotary kiln/afterburner type unit with 4 PIC formation zones being designated. Table 2.1 shows how the conditions within each zone may be distinctly different, resulting in different mechanisms of PIC formation being dominant in each zone. These general reaction classes have been defined that include most of the PIC formation pathways that can occur within an incinerator. These are: 1) concerted unimolecular eliminations, 2) complex radical-molecule pathways, and 3) radical-radical (atom) and radical-molecule association reactions.

Although there may be some contribution of each mechanism in each zone, chemical kinetic theory suggests that mechanism 1 will dominate in the preflame zone, mechanism 2 will dominate in the flame and postflame zones, and mechanism 3 will dominate in the cooler zones downstream of the main combustor unit. As the following discussion will demonstrate, these reactions are zero, first, and second-order with respect to the radical concentration and very different types of PICs may be formed in each zone. The nature and yield of PICs that are formed will depend upon the conditions in a particular incinerator as well as the elemental and molecular chemical composition of the waste/fuel feed.

Mechanism 1: Concerted Unimolecular Elimination Reactions

Concerted molecular elimination to form stable PICs is a subclass of unimolecular reactions, viz., reactions only involving the parent compound.[29,30] Since a second molecule or radical is not involved in the reaction, the PIC yield is dependent only upon time, temperature, and the

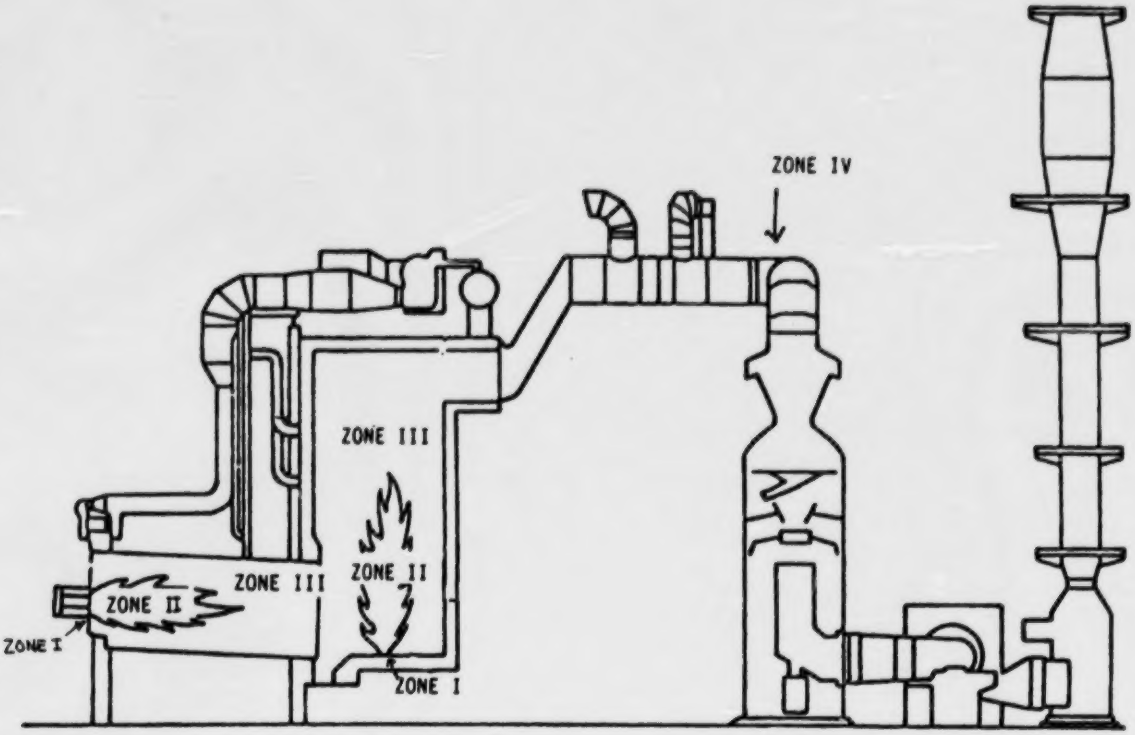

ZONE IV
ZONE III
ZONE II
ZONE III
ZONE II
ZONE I
ZONE I

Figure 2.1. PIC formation zones in a hazardous waste incinerator.
Zone I - Preflame
Zone II - Flame
Zone III - Postflame
Zone IV - Cool

TABLE 2.1

DESCRIPTION OF HAZARDOUS WASTE INCINERATOR PIC FORMATION ZONES AND DOMINANT PIC FORMATION MECHANISMS

ZONE	REACTION CONDITIONS	PIC MECHANISMS[a]
Preflame Zone	$T = 200\text{-}1000°C$ $t_r << 1$ s $[O_2] \sim 0\text{-}50\%$ excess air[e]	Mechanism 1[b] Mechanism 2[c] Mechanism 3[d]
Flame Zone	$T = 1000\text{-}1800°C$ $t_r << 1$ s $[O_2] \sim 50\%$ excess air[e]	Mechanism 2 Mechanism 1 Mechanism 3
Postflame Zone	$T = 600\text{-}1100°C$ $t_r = 1\text{-}10$ s $[O_2] \sim 50\text{-}100\%$ excess air[e]	Mechanism 2 Mechanism 1 Mechanism 3
Cool Zone (APCD and stack)	$T = 80\text{-}600°C$ $t_r = >>10$ s $[O_2] \sim 3\text{-}9\%$	Mechanism 3

[a] PIC formation mechanisms are listed in decreasing order of importance.

[b] Concerted unimolecular elimination reactions.

[c] Radical-molecule reactions.

[d] Radical-radical (atom) and radical-molecule association reactions.

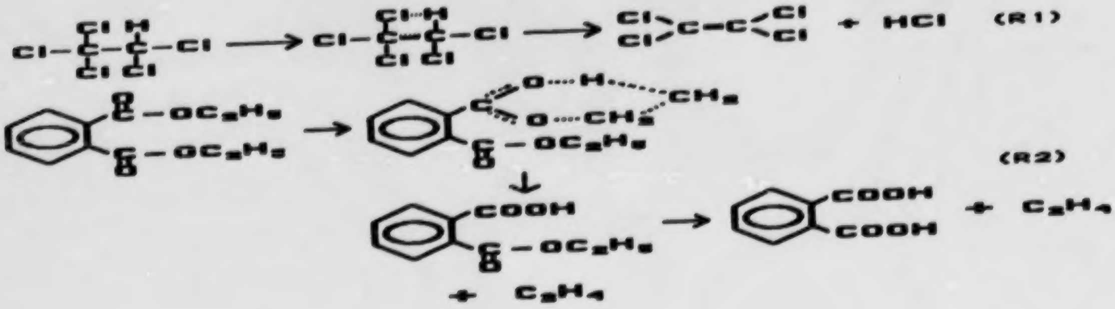
[e] Average values; localized deviations due to poor waste/air mixing result in pyrolytic combustion conditions.

Arrhenius parameters of the molecular elimination reaction:

$$\% \text{ PIC Yield} = [PIC]/[POHC]_0 \times 100 = 100[1-\exp(-At \exp(-Ea/RT)) \qquad \text{(Eqn 1)}$$

where: $[POHC]_0$ = initial concentration of parent POHC; [PIC] = concentration of PIC, t = reaction time; A = Arrhenius pre-exponential factor; Ea = Arrhenius activation energy; T = the reaction temperature; and R = ideal gas constant.

Examples of known concerted unimolecular elimination reactions which produce stable products include what are referred to as four-, five- and six-center processes. Rxn 1 presents the conversion of pentachloroethane (C_2HCl_5) to tetrachloroethene (C_2Cl_4) and hydrogen chloride (HCl) as an example of a four-center process. Rxn 2 presents the conversion of diethyl phthalate to phthalic acid and ethene (C_2H_4) as an example of a six-center process.[30]



The former is of particular interest because it illustrates a pathway where a fragile POHC may decompose to form large yields of a thermally stable PIC.[31] The latter is also of interest because it demonstrates how phthalates are easily degraded and should not be observed in incinerator effluents. In light of these degradation pathways, reported observations of phthalate emissions are likely the result of sampling or analytical error or ubiquitous sources, e.g., outgassing of phthalates in plasticizers.[17]

Table 2.2 presents a list of Arrhenius parameters for POHCs of interest to incineration that have been experimentally shown to decompose by four- or

TABLE 2.2

SOME EXPERIMENTALLY DOCUMENTED UNIMOLECULAR ELIMINATION PIC FORMATION PATHWAYS

POHC	PIC	Pathway	Ea (kcal/mol)	A (1/s)	T_{99} (2) (°C)
1,2-Dibromo-3-chloropropane	1-Bromo-2-chloropropene	HBr Elim.	51.3	4.17E13	572
1,1-Dichloroethane	Chloroethene	HCl Elim.	53.5	3.16E13	616
1,2-Dichloroethane	Chloroethene	HCl Elim.	58.0	3.98E13	684
1,1-Dichloro propane	Chloropropene	HCl Elim.	53.5	3.16E13	617
1,2-Dichloropropane	Chloropropene	HCl Elim.	54.9	6.31E13	619
1,3-Dichloropropane	Chloropropene	HCl Elim.	54.9	4.20E13	631
2,2-Dichloropropane	Chloropropene	HCl Elim.	50.0	1.00E14	528
1,2-Dibromoethane	Bromoethene	HBr Elim.	51.3	4.17E13	572
DDT	DDE	HCl Elim.	53.2	7.94E12	654
Diethylphthalate	Phthalic acid	C_2H_4 Elim.	48.0	7.78E12	564
Di-n-butylphthalate	Phthalic acid	C_4H_8 Elim.	46.0	3.08E12	556
Di-n-octylphthalate	Phthalic acid	C_4H_8 Elim.	46.0	3.08E12	556
Pentachloroethane	Tetrachloro ethene	HCl Elim.	59.7	1.26E14	676
Propanenitrile	Ethene	HCN Elim.	67.8	2.00E14	789
1,1,1,2-Tetrachloroethane	Trichloroethene	HCl Elim.	54.0	1.26E14	586
1,1,2,2-Tetrachloroethane	Trichloroethene	HCl Elim.	58.0	1.26E14	649
1,1,1-Trichloroethane	1,1-Dichloroethene	HCl Elim.	54.2	1.26E14	589
1,1,2-Trichloroethane	1,1- and 1,2-Dichloroethene	HCl Elim.	57.0	1.26E13	677
1,2,3-Trichloropropane	Dichloropropene	HCl Elim.	55.0	8.45E13	613
Vinyl chloride	Acetylene	HCl Elim.	69.3	1.00E14	837

six-center processes. The reaction rates for most of these molecules are all energetically favorable under incineration conditions with an extent of reaction greater than 99% at temperatures below 700°C. The elimination of HCl from vinyl chloride (C_2H_3Cl) to form acetylene (C_2H_2) has a higher decomposition temperature, in part due to its higher activation energy. The π bond character of the H and Cl atoms participating in the elimination process is responsible for the higher activation energy, and may mean that HCl elimination from alkenes is relatively rare. Because these PIC formation pathways occur so rapidly, the resultant PIC can experience almost the full gas-phase residence time experienced by the parent POHC. Thus, PICs produced by molecular elimination may undergo decomposition resulting in secondary PIC formation, or the reaction may proceed to the formation of thermodynamically stable combustion endproducts.

Mechanism 2: Complex Radical-Molecule Pathways

Examples of bimolecular reactions that result in stable PIC formation are radical-molecule reactions. Once the decomposition of the parent POHC is initiated and a pool of reactive radicals is formed, radical-molecule reactions will usually be the dominant pathway for PIC formation. Hydroxyl (OH) radicals are the dominant reactive species under most practical stoichiometric and oxidative conditions, while hydrogen (H) atoms are the dominant reactive species under pyrolytic conditions.[20,25,28] In addition, polyatomic organic radicals are also believed to play an important role in the formation of PICs that are of higher molecular weight than the parent compound. Highly halogenated wastes can result in generation of significant quantities of fluorine (F), chlorine (Cl), bromine (Br), and iodine (I) atoms. These species can be quite reactive and we include a discussion of Cl reactions as an example of the reactions of halogens. However, it must be remembered that there are differences which must be examined on a case by case basis. We first discuss simple elementary reactions of POHCs that can directly result in formation of stable PICs or stable radicals which result in PIC formation through subsequent simple or complex reaction pathways.

Bond Fission

Although simple bond fission of stable molecules does not directly form molecular PICs, it can in some cases form stable radicals that form molecular PICs by recombination and condensation reactions (cf. Rxn 3):

$$CCl_4 \dashrightarrow CCl_3 + Cl \qquad \Delta H^\circ_{R,300} = 70.3 \text{ kcal/mole} \qquad \text{(Rxn 3)}$$

Numerical comparisons of the rate of bimolecular radical attack by such species as OH, H, and Cl versus the rates of bond fission for typical molecules indicate that bond fission will only be a significant mode of POHC destruction when the bond dissociation energy (D_0) is $\leq$ 85 kcal/mole.[20,25]

Table 2.3 gives representative bond energies for a range of compounds containing carbon, hydrogen and various heteroatoms. Several important observations are evident concerning the stability and decomposition pathways of common toxic organic compounds:

1. C-Br bonds are weaker than C-Cl bonds which are weaker than C-H bonds in homologous molecules;
2. Increasing halogen substitution generally decreases the strength of the C-Cl(Br), C-H, and C-C bonds;
3. When resonance-stabilized radicals are formed, bond strengths are significantly lowered;
4. Bond dissociation energies and heats of formation at 298 K ($\Delta H^\circ_{f,298}$) of many important radicals are not available.

The last observation is particularly important because the heat of reaction ($\Delta H^\circ_{R,298}$) for bond fission reactions is equal to D_0 and related to the activation energy ($Ea(T) = \Delta H^\circ_{R,298} + \Delta Cp^\circ (T - 298) + 1/2\ RT$).[32] The heat of formation (ΔH_f°) of stable molecules may be approximated by group additivity methods; however, the necessary data to calculate ΔH_f° for many halogenated radicals is not generally available.[29] Arrhenius pre-exponential factors (A (T)) may be calculated by transition state theory (TST), estimated by comparison to similar compounds, or estimated from general trends available from theory and experiment. For simple atom

TABLE 2.3

BOND DISSOCIATION ENERGIES FOR SOME ORGANIC MOLECULES R'-R"[a]

PARAMETERS	(52.1) H	(18.9) F	(28.9) Cl	(26.7) Br	(9.43) OH	(46±1) NH_2	(4.2) OCH_3	(35.1±0.1) CH_3	(78.6±2) C_6H_5
(35.1±0.1)[b]CH_3	105.1±0.2	109.9±1	84.6±0.2	70.9±0.3	92.3±1	84.9±1.1	83.3±1	90.4±0.3	101.8±2
(26±1) C_2H_5	98.2±1	107.7±1	79.9±1	67.8±1	91.5±1	84	81.8±1	85.8±1	97.4±2
(18±1) i-C_3H_7	95.1±1	106.5±1.1	80.7±1.4	68.4±1.2	92	84	82	85.7±1	95.9±2
(79±2) C_6H_5	110.9±2	125.7±2	95.7±2	80.5±2	112	102±2	100	101.8±2	116
(11.4) C_6H_5O	86.5							63.8±1	
(34.7) C_6H_5NH	88±2					52.3±2		71.4±2	81.1±2.5
(48±2) $C_6H_5CH_2$	88.0±1		72.2±1.5	57.6±1.5	77	71.1±1	70	75.8±1	77
(67.5±2)-C=C	107±2		91				95	98.8±2	112
(39.1±1.5)-C-C=C	86.3±1.5				80		(60)[c]	74.4±1	78
(-5.8±0.4)CH_3CO	86.0±0.8	118	82.5		108	101	97	81.2±1	93.5±1.5
(-4.1)CH_3CH_2O	104.2±1				43		38	82.7±1	99
(104±2) CN	123.8±2	112.3±1.2	100.8±1.2	87.8±1.2				121.8±2	131±2
(58.5±2.5)CH_2CN	93±2.5							81.3±3	
(35.7±2)CH_2NH_2	93.3±2							82.2±2	93.3±2
(28.3) CH_2Cl	100.9±2		80.1						
(24.1) $CHCl_2$	99.0±2		77.6						
(19±1) CCl_3	95.8±1	101.9±2.3	73.1±1.8	55.3±1					
(8.4±2) C_2Cl_5	95±2								
(-111.7±3.6)CF_3	106.7±1	130.5±3	86.2±3	70.6±3					
(-23) $CFCl_2$		110±6	73±2						
(-64.3±2)CF_2Cl	101.6±1	123±2.2	76±2	64.5±1.5					
(-41.5) CH_2Br	102.0±2								
(54.3) $CHBr_2$	103.7±2								
(---) CBr_3	96.0±1.6			56.2±1.8					
(55.0±1.6)CH_2I	103±2								
(79.9±2.2)CHI_2	103±2								

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[a] All values are in kcal/mole.

[b] Values in parenthesis near radicals are $\Delta H^{\circ}_{f,298}$.

[c] Values in parenthesis are estimates.

detachment, $A \sim 10^{15}$ 1/s, while for fission into complex radicals A varies between 10^{15} and 10^{17} 1/s. Order of magnitude increases are possible for highly chlorinated species. Table 2.4 presents some representative Arrhenius parameters for bond fission reactions that may be used to estimate rates of other reactions.

From the bond dissociation energy and A factor, it is possible to make a prediction of which radical species may be formed. However, only stable radicals are likely to survive to form stable molecular products. The discussion of radical stability is included as part of the discussion of mechanism 3.

Hydroxyl Radical Attack

Hydroxyl radical is the dominant reactive species under stoichiometric and slightly oxygen-rich ($0.5 \leq \Phi \leq 1.0$) conditions. In principle, three reaction pathways can be considered: 1) H or Cl abstraction from saturated molecules (and unsaturated molecules at high temperatures), 2) H or Cl displacement from unsaturated molecules, and 3) addition to unsaturated molecules at low temperatures. Although addition may occur at or near room temperature, the entropy change drives the reverse reaction at combustion temperatures. Consequently, we do not consider it further.

H abstraction (by OH) is well documented and extremely fast for most species, the driving force being the strength of the H-OH bond ($D_0 = 117$ kcal/mole) which is formed which results in a highly exothermic reaction (cf. Rxn 4):

$$C_2HCl_3 + OH \dashrightarrow C_2Cl_3 + H_2O \qquad [\Delta H^\circ_{R,300} = -17.1 \text{ kcal/mole}] \qquad \text{(Rxn 4)}$$

The rate of H abstraction generally tracks the strength of the bond being broken. α-Cl substitution weakens the C-H bond, resulting in faster H abstraction in, for example, CH_2Cl_2 versus CH_3Cl. Somewhat anomalously, β-Cl substitution decreases that rate of H abstraction resulting in slower H

TABLE 2.4

ARRHENIUS PARAMETERS[a] FOR BOND FISSION REACTIONS

Rxn	$A(s^{-1})$	E_a(kcal mol^{-1})	T_{99}(2)(°C)	Reference[1]
$CH_4 \rightarrow CH_3+H$	3.8×10^{15}	104.5	1227	a
$C_2H_6 \rightarrow CH_3+CH_3$	5.0×10^{16}	89.4	922	a
$C_2H_4 \rightarrow C_2H_3+H$	2.0×10^{16}	110.0	1193	b
$C_6H_6 \rightarrow C_6H_5+H$	2.5×10^{17}	116.2	1217	c
$C_6H_5CH_3 \rightarrow C_6H_5CH_2+H$	1.3×10^{16}	94.4	1036	d
$CH_3Cl \rightarrow CH_3+Cl$	2.5×10^{15}	82.5	925	e
$C_2Cl_6 \rightarrow CCl_3+CCl_3$	6.0×10^{17}	68.4	585	f
$C_2Cl_6 \rightarrow C_2Cl_5+Cl$	1.0×10^{16}	69.1	692	f
$C_2HCl_3 \rightarrow C_2HCl_2+H$	7.0×10^{15}	84.0	912	g
$C_2Cl_4 \rightarrow C_2Cl_3+Cl$	4.5×10^{14}	80.0	950	g
$C_6H_5Cl \rightarrow C_6H_5+Cl$	1.2×10^{14}	90.0	1160	h
$C_2F_6 \rightarrow CF_3+CF_3$	1.9×10^{17}	92.0	915	i
$C_6H_5Br \rightarrow C_6H_5+Br$	2.0×10^{15}	80.9	910	j
$C_2H_5I \rightarrow C_2H_5+I$	4.0×10^{14}	53.2	543	j

[a] Reactions are assumed to be at their high-pressure limit.

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abstraction in, for example, CH_3CH_2-H versus CCl_3CH_2-H. Table 2.5 summarizes Arrhenius parameters for H abstraction (by OH) for some important species.

Cl abstraction (by OH) forms a very weak HO-Cl bond (D_0 = 57 kcal/mole); consequently this reaction is endothermic and very slow. It is not an important reaction under any condition except when no other reaction pathway is available. Since H is preferentially abstracted over Cl, the result in an increased halogen to hydrogen atom ratio in the resulting radical. Depending on the H:Cl atom ratio, association reactions can reform the original molecule by reaction with H or increase chlorination by reaction with Cl. As in the case of bond fission, the radical must be stable enough to survive and undergo the association process in order to directly form a molecular PIC.

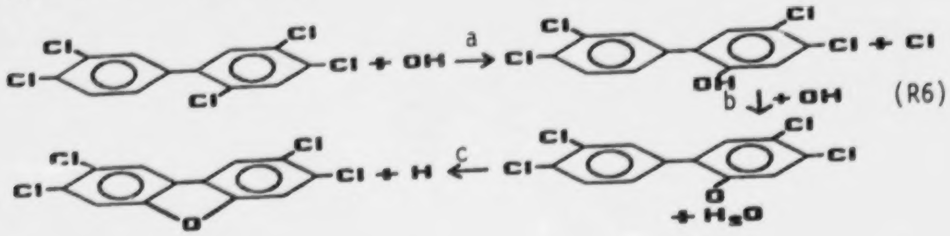
We next consider H and Cl displacement (by OH). These are important from a PIC formation perspective in that they directly form stable molecular PICs without going through a radical intermediate (cf. Rxn 5):

$$C_2Cl_4 + OH \dashrightarrow C_2Cl_3OH + Cl \qquad \text{(Rxn 5)}$$

We need not consider displacement reactions at saturated sites, since it has generally been observed that the initial step in a displacement reaction is electrophilic addition to the π electron structure of alkenes, alkynes, or aromatics.

The reverse of H displacement by OH (OH displacement by H) is strongly favored by equilibrium, thus we need not consider H displacement further. In contrast, Cl displacement (by OH) is strongly exothermic and there are no apparent thermodynamic barriers to this reaction. Unfortunately, there are no kinetic data available which have been attributed to this type of reaction. This is an important reaction in that it results in dechlorination of organic compounds. In the case of the chlorinated benzenes it can result in phenol (or chlorinated phenol) formation. It is interesting to note that the dominant route for the decomposition of benzene under oxidative conditions has been suggested to involve attack by OH or O atoms followed by formation of the phenoxy radical ($C_6H_5O^\cdot$).[33] $C_6H_5O^\cdot$ may then further decompose to form carbon monoxide (CO) and cyclopentadienyl radical $(C_5H_5)^\cdot$. $C_5H_5^\cdot$ may then react with oxygen to form cyclopentadienonyl radical $(C_5H_5O^\cdot)$, which will decompose to butadienyl radical $(C_4H_5^\cdot)$ and CO. Once ring opening has occurred, other stable organic products such as C_2H_2 and C_2H_4 may form. This pathway is representative of the oxidation of substituted aromatic species after any side chains or other functional groups have been removed.

An important example of abstraction and displacement reactions of OH include the formation of polychlorinated dibenzofurans (PCDFs) from 2,3′,4,4′,5-pentachlorobiphenyl (PCB)[15], as depicted in Rxn 6 and Figure 2.2. Cl displacement by OH has been proposed as the first step. This is followed with H abstraction by OH forming the resonance stabilized tetrachlorobiphenoxyl radical. The third step is ring closure forming 2,3,7,8-PCDF with percent



(R6)

yields of products. It has recently been confirmed through Quantum RRK calculations that step c is faster when Cl (as opposed to H) is displaced by the phenoxy radical in agreement with the exothermicity of the reaction.[60] Thus, formation of PCDFs from PCBs is expected to proceed more rapidly with increasing number of Cl substituents in the position ortho to the C-C inter-ring bond.

Finally, we note that the rate of abstraction by O atoms is generally expected to parallel that of OH. However, H displacement (by O) is exothermic and steps a and b (Rxn 6) could be replaced by Cl displacement (by O) to form the same product (or H displacement to form penta-CDF). However, the concentration of O atoms is usually low in all but the most fuel-lean systems. Still, the formation of ultra-trace concentrations of PICs such as PCDFs could be influenced by this O atom mechanism.

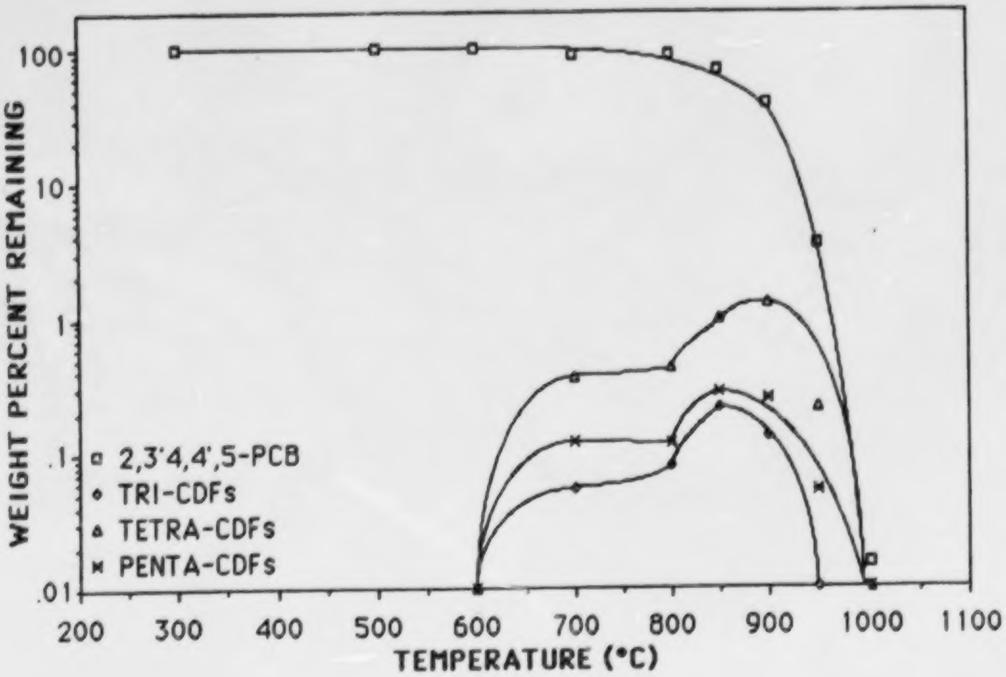


Figure 2.2. PCB Degradation and PCDF Formation/Destruction Profiles. The Gas-phase Residence Time was 2.0 s and the Fuel/Air Equivalence Ratio was 1.0.

Hydrogen Atom Attack

Hydrogen atoms may react with halocarbons at high temperatures by H (or Cl) abstraction or Cl displacement. Previous research suggests that significant emissions from hazardous waste incinerators may be due to pyrolysis pockets in poorly mixed regions of the system.[26-28] Since H atoms are expected to be the dominant reactive species under pyrolytic conditions, its reactions are extremely important for POHC destruction and PIC formation.

Both H and Cl abstraction (by H) are exothermic processes and are thus thermodynamically allowed, although both are slower than H abstraction by OH (cf. Tables 2.5 and 2.6). Unfortunately, it is not clear whether Cl or H is preferentially abstracted from chlorocarbons (see Rxns 7a and 7b). Limited data suggest that H abstraction is faster and increases slightly with Cl substitution.[34]

$H + CCl_3H \dashrightarrow CCl_3 + H_2 \qquad \Delta H_{R,298} = -8.4$ kcal/mole (Rxn 7a)

$H + CCl_3H \dashrightarrow CCl_2H + HCl \qquad \Delta H_{R,298} = -25.4$ kcal/mole (Rxn 7b)

For chlorinated aromatic species, Cl displacement by H is a major pathway of destruction[28,35] (cf. Rxn 8):

$H + \phi\text{-}Cl \dashrightarrow \phi\text{-}H + Cl \qquad \Delta H_{R,298} = -15.7$ kcal/mole (Rxn 8)

This reaction is also important in that it directly forms a less chlorinated PIC. It has also been shown that other functional groups such as CH_3, NH_2, and OH are readily displaced, resulting in formation of benzene[36-38] (cf. Rxn 9a):

$H + \phi\text{-}OH \dashrightarrow \phi - H + OH \qquad \Delta H_{R,298} = 0.2$ kcal/mole (Rxn 9a)

$H + \phi\text{-}OH \dashrightarrow \phi - O + H_2 \qquad \Delta H_{R,298} = -17.6$ kcal/mole (Rxn 9b)

Some abstraction of H was also observed on the substituent resulting in the formation of a resonance-stabilized radical (cf. Rxn 9b). The difference in the rate of displacement follows the trend:

Table 2.5 Summary of Experimental Rate Data for H Abstraction by OH

Reaction	A (L/mol-s)	n	Ea (cal/mol)	T_{99}[1] (°C)	Ref.[2]
OH + HCl --> H_2O + Cl	2.25E+09	0.0	1021	930	a
OH + H_2 --> H_2O + H	6.40E+03	2.0	2961	930	b
OH + CH_4 --> CH_3 + H_2O	4.20E+03	2.0	2547	940	c
OH + C_2H_6 --> C_2H_5 + H_2O	8.40E+03	2.0	918	875	c
OH + C_2H_4 --> C_2H_3 + H_2O	2.90E+03	2.0	2235	955	c
OH + C_6H_6 --> C_6H_5 + H_20	2.80E+03	2.0	1079	930	c
OH + CH_3Cl --> CH_2Cl + H_2O	5.04E+05	1.4	2389	905	d
OH + CH_2Cl2 --> $CHCl_2$ + H_2O	9.15E+04	1.6	1236	895	d
OH + $CHCl_3$ --> CCl_3 + H_2O	1.16E+01	2.8	188	910	d
OH + CH_3CCl_3 --> CH_2CCl_3 + H_2O	3.60E+03	2.0	2244	940	c
OH + CH_3F --> CH_2F + H_2O	3.31E+03	2.0	1997	945	c
OH + CH_3Br --> CH_2Br + H_2O	7.04E+02	2.0	588	990	c
OH + HCN --> CN + H_2O	7.22E+07	0.0	795	>1100	c
OH + CH_3CN --> CH_2CN + H_2O	4.08E+08	0.0	2067	1045	c

Footnotes:

1. T_{99} defined as temperature (°C) for 99% destruction of reactant for a residence time of 2.0 s; OH concentration calculated from equilibrium stoichiometric combustion of reactant with following elemental composition: CH_2Cl_2.

2. Bibliographic sources.

[a] Baulch, D.L., Duxury, J., Grant, S.J., and Montague, D.C. (1981) J. Phys. Chem. Ref. Data, Supplement 1,10.

[b] Tsang, W. and Hampson, R.F., ibid, 15, 1087.

[c] Atkinson, R. (1986) Chem. Rev. 86, 69.

[d] Taylor, P.H., D'Angelo, J.A., Martin, M.C., Kasner, J.H., and Dellinger, B. (1989) Int. J. Chem. Kinet., 21, 829.

Table 2.6 Summary of Experimental Rate Data for H (and Cl) Abstraction by H

Reaction	A (L/mol-s)	n	Ea (cal/mol)	T_{99}[1] (°C)	Ref.[2]
$H + HCl \rightarrow Cl + H_2$	8.00E+09	0.0	3398	920	a
$H + CH_4 \rightarrow CH_3 + H_2$	2.25E+01	3.0	8756	960	b
$H + C_2H_4 \rightarrow C_2H_3 + H_2$	1.33E+03	2.5	12241	1020	b
$H + C_6H_5CH_3 \rightarrow C_6H_5CH_2 + H_2$	1.20E+11	0.0	8223	885	c
$H + C_6H_5NH_2 \rightarrow C_6H_5NH + H_2$	1.80E+11	0.0	11617	935	c
$H + C_6H_5OH \rightarrow C_6H_6O + H_2$	1.10E+11	0.0	12400	975	c
$H + CH_3Cl \rightarrow CH_2Cl + H_2$	3.70E+10	0.0	9300	965	d
$H + CH_3Cl \rightarrow CH_3 + HCl$	3.70E+10	0.0	9300	965	e
$H + CH_3Br \rightarrow CH_3 + HBr$	5.37E+10	0.0	4300	845	e
$H + CH_2Cl_2 \rightarrow CH_2Cl + HCl$	1.07E+10	0.0	6101	960	e
$H + p\text{-}C_6H_4ClCH_3 \rightarrow p\text{-}C_6H_4ClCH_2 + H_2$	9.60E+10	0.0	8475	905	c
$H + CF_3Cl \rightarrow CF_3 + HCl$	1.58E+10	0.0	8102	985	e
$H + CH_2F_2 \rightarrow CHF_2 + H_2$	1.30E+10	0.0	9401	1025	e

Footnotes:

1. T_{99} defined as temperature (°C) for 99% destruction of reactant for a residence time of 2.0 s; H concentration taken as equal to OH concentration calculated from equilibrium stoichiometric combustion of reactant with following elemental composition: CH_2Cl_2.

2. Bibliographic sources.

[a] See (a) Table 2.5

[b] See (b) Table 2.5

[c] Cui, J.P., He, Y.Z., and Tsang, W. (1989), J. Phys. Chem. 93, 724.

[d] Westenberg, A.A. and de Haas, N. (1975) J. Chem. Phys., 62, 3321.

[e] Kerr, J.A. and Moss, S.J. eds., "Handbook of Bimolecular and Termolecular Gas Reactions, Vol. II," CRC Press, Boca Raton, FL, 1981.

toluene > aniline > phenol > chlorobenzene

which is in general accord with expected phenyl-substituent bond energy, although these values are not known with accuracy. There is generally not much difference in the rates of H abstraction and side chain displacement for any of these species (cf. Tables 2.6 and 2.7). The main observation for the displacement mechanism is the trend toward dechlorination and removal of side chain substituents with the resultant formation of benzene.

Chlorine Atom Attack

Chlorine atoms may react with chlorocarbons via H (or Cl) abstraction and H displacement. For alkenes, alkynes and aromatics, substituent groups can be displaced. Chlorine abstraction, resulting in Cl_2 formation, is highly endothermic and need not be considered further. H displacement (by Cl) is also thermodynamically unfavorable, with the reverse reaction being dominant. Chlorine atom displacement of other substituents, e.g., CH_3, NH_2, and OH, is usually slightly endothermic, but may occur to a modest extent if the Cl concentration is very high. However, we generally expect H atom abstraction to be the dominant reaction for Cl atom attack (cf. Rxn 10):

$$\phi + Cl \dashrightarrow \phi^{\cdot} + HCl \qquad \Delta H_{R,298} = 7.8 \text{ kcal/mole} \qquad \text{(Rxn 10)}$$

Based on limited data at temperatures below those typically found in incinerators, H abstraction (by Cl) is slightly faster than by OH (cf. Tables 2.5 and 2.8). This is primarily due to a large A factor as would be expected for abstraction by atoms versus diatomics, e.g., OH, and is in the opposite direction of the enthalpies of reaction.

This discussion of elementary reactions involving major radicals or atoms and POHCs suggests that stable molecular PICs are most frequently formed by H atom displacement reactions of Cl and other substituents from alkene, alkyne, and aromatic species. Organic radicals are predominantly formed by OH, H, or Cl abstraction of H.

Table 2.7 Summary of Experimental Rate Data for Displacement by H

Reaction	A (L/mol-s)	n	Ea (cal/mol)	T_{99}[1] (°C)	Ref.[2]
H + 1,2,3-$C_6H_3Cl_3$ --> 1,3-$C_6H_4Cl_2$ + Cl	1.90E+10	0.0	5870	925	a
H + 1,2,3-$C_6H_3Cl_3$ --> $C_6H_4Cl_2$ + Cl	3.70E+09	0.0	3688	970	a
(Data reflects Cl displacement from both the 1 and 3 positions)					
H + p-$C_6H_4ClCH_3$ --> C_6H_5Cl + CH_3	3.50E+10	0.0	7373	925	b
H + $C_6H_5CH_3$ --> C_6H_6 + CH_3	1.20E+10	0.0	5123	935	a
H + 1,2-$C_6H_4Cl_2$ --> C_6H_5Cl + Cl	9.20E+10	0.0	10325	945	a
H + 1,3-$C_6H_4Cl_2$ --> C_6H_5Cl + Cl	4.60E+10	0.0	9024	950	a
H + $C_6H_5NH_2$ --> C_6H_6 + NH_2	2.20E+10	0.0	7422	950	a
H + p-$C_6H_4ClCH_3$ --> $C_6H_5CH_3$ + Cl	4.80E+10	0.0	9529	960	b
H + C_6H_5OH --> C_6H_6 + OH	2.20E+10	0.0	7929	970	a
H + C_6H_5Cl --> C_6H_6 + Cl	2.20E+10	0.0	9004	985	a

Footnotes:

1. T_{99} defined as temperature (°C) for 99% destruction of reactant for a residence time of 2.0 s; H concentration taken as equal to OH concentration calculated from equilibrium stoichiometric combustion of reactant with following elemental composition: CH_2Cl_2.

2. Bibliographic sources.

[a] Cui, J.P., He, Y.Z., and Tsang, W. (1989) J. Phys. Chem. 93, 724.

[b] Atkinson, R., Bulch, D.L., Cox, R.A., Hampson, R.F., Ken, J.A., and Troe, J. (1989) J. Phys. Chem. Ref. Data 18, 1089.

Table 2.8 Summary of Experimental Rate Data for H Abstraction by Cl

Reaction	A (L/mol-s)	n	Ea (cal/mol)	T_{99}[1] (°C)	Ref.[2]
Cl + H_2 --> H + HCl	1.45E+10	0.0	4372	910	a
Cl + H_2O --> OH + HCl	1.70E+10	0.0	17229	>1100	a
Cl + CH_4 --> CH_3 + HCl	1.10E+04	2.0	1490	875	a
Cl + C_2H_6 --> C_2H_5 + HCl	4.60E+10	0.0	179	<800	b
Cl + C_2H_4 --> C_2H_3 + HCl	3.00E+10	0.0	2802	840	c
Cl + CH_3Cl --> CH_2Cl + HCl	2.00E+10	0.0	2504	850	b
Cl + $CHCl_3$ --> CCl_3 + HCl	1.60E+10	0.0	3319	875	d
Cl + CH_3F --> CH_2F + HCl	2.90E+09	0.0	1500	925	e
Cl + CH_3CCl_3 --> CH_2CCl_3 + HCl	2.50E+09	0.0	3600	990	e

Footnotes:

1. T_{99} defined as temperature (°C) for 99% destruction of reactant for a residence time of 2.0 s; Cl concentration taken as equal to OH concentration calculated from equilibrium stoichiometric combustion of reactant with following elemental composition: CH_2Cl_2.

2. Bibliographic sources.

[a] Baulch, D.L., Duxburg, J., Grant, S.J., and Montague, D.C. (1981) J. Phys. Chem. Ref. Data, Supplement 1, 10.

[b] See (b) above

[c] Parmar, S.M. and Benson, S.W. (1988) J. Phys. Chem. 91, 2652.

[d] Chiltz, G., Goldfinger, P., Huybrechts, G., Martens, G., and Verbeke, G. (1963) Chem. Rev. 63, 355.

[e] Kerr, J.A. and Moss, S.J., eds., "Handbook of Bimolecular and Termolecular Gas Reactions, Vol. 11," CRC Press, Boca Raton, FL 1981.

The displacement reactions result in less substituted (e.g., less chlorinated) PICs that are almost always more stable in a pyrolytic environment than the parent POHC and usually more stable in an oxidative environment. Benzene and phenol are examples of important PICs that can be formed by displacement reactions. Moderately stable radicals formed by abstraction reactions can further react to produce very complex PICs. These reactions are discussed in the following sections.

Molecular Growth Reactions

The organic radicals that are formed from the elementary reactions discussed in the previous sections can undergo a variety of secondary reactions. Not only can they recombine with atoms to form PICs that are generally of lower molecular weight than the parent species, they can also undergo molecular growth or "condensation" type reactions that result in formation of higher molecular weight PICs.

In shock-tube studies of the chlorinated methanes, Frenklach, et al[39] observed high yields of soot formation (versus hydrocarbons), with methylene chloride (CH_2Cl_2) displaying a special propensity for soot formation (cf. Figure 2.3). The proposed mechanism involved formation of C_2H_2 via HCl elimination from C_2H_3Cl, a proposed reaction intermediate. Acetylene could then react with allenyl (C_3H_3) radicals or with various C_2-species to ultimately form soot. A study by Senser et al[40] of the combustion of CH_2Cl_2 in fuel-lean ($\phi = 0.8$) CH_4-air flames has also shown the propensity for formation of PICs of higher molecular weight than the parent (cf. Figure 2.4). These results indicated that as the Cl:H ratio of the fuel mixture was increased, rapid destruction of heavily hydrogenated species (e.g., C_2H_6, C_2H_4) occurred and higher yields of the suspected soot precursor acetylene were observed. The yield of C_2-chlorocarbons (C_2HCl_3 and C_2Cl_4) also increased with increasing Cl:H ratio. Other studies by this group[41,42] have demonstrated similar behavior for fuel mixtures incorporating the other chlorinated methanes.

Trichloroethene (C_2HCl_3) has been extensively studied in fuel-lean and fuel-rich premixed flat-flames by Senkan and co-workers.[11,43-46] These

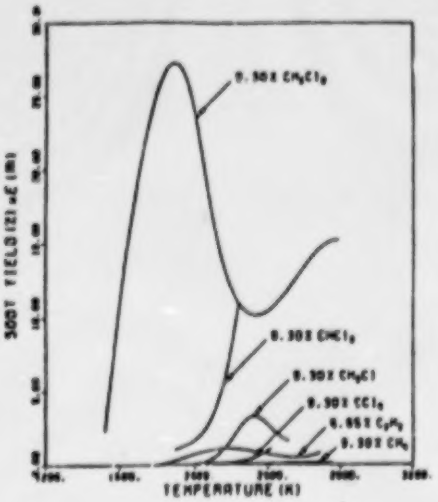


Figure 2.3. Soot yields versus temperature in the pyrolysis of chlorinated methanes at a reaction time of 1.0 ms.

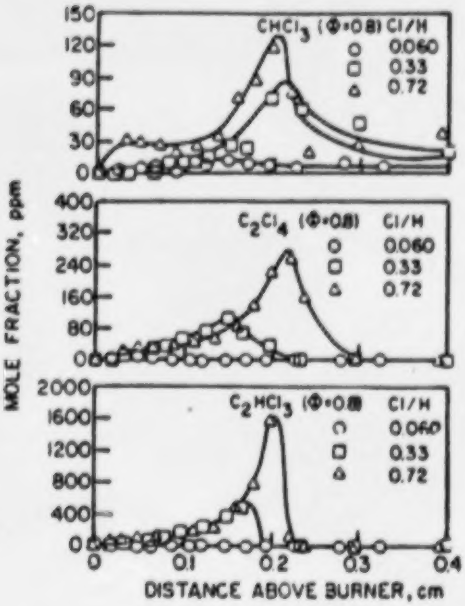


Figure 2.4. $CHCl_3$, C_2Cl_4, and C_2HCl_3 mole fractions vs. distance above the burner surface at a constant ϕ of 0.80.

studies also revealed the formation of high molecular weight PICs, which in this case were perchlorinated, e.g., hexachloroethane (C_2Cl_6), hexachloropropene (C_3Cl_6), tetrachloroethene (C_2Cl_4), and hexachlorobenzene (C_6Cl_6) (cf. Figure 2.5). These studies have resulted in the most complete elementary kinetic modeling of the combustion of a single chlorinated species. As shown in Table 2.9, the 147 step model addresses the formation of observed oxidative products $COCl_2$, $CHCl_2COCl$ and CCl_3COCl, as well as pyrolysis products $CHCl_3$, CCl_4, C_2Cl_2, C_2HCl_5, C_2Cl_4, C_2Cl_6, C_3HCl_5, C_3Cl_6, C_4Cl_6, and C_6Cl_6. Chemically activated addition reactions (with subsequent Cl elimination) were proposed for the formation of many of the pyrolysis products as illustrated in Rxn 11 for the formation of C_4HCl_5:

$$C_2Cl_3 + C_2HCl_3 \dashrightarrow C_4HCl_6^* \dashrightarrow C_4HCl_5 + Cl \qquad \text{(Rxn 11)}$$

Mechanisms for formation of C_6Cl_6 were presented which are similar to the mechanisms originally proposed by Dellinger and co-workers for C_6Cl_6 formation from $CHCl_3$[47,48] and CCl_4[47,48] and more recently C_2Cl_4.[49] These results also confirm the much earlier flow reactor studies of Goodall and Howlett[50] who also observed formations C_6Cl_6 from C_2HCl_3 at temperatures of 490°C and attributed its formation to a radical chain mechanism involving C_2Cl_2.

Extensive flow reactor pyrolysis studies have done much to clarify the mechanism of formation of high molecular weight chlorinated species from simple chlorinated hydrocarbon precursors. Relatively low yields of aromatic species were reported from the pyrolysis of CH_3Cl,[51] while higher yields of chlorinated aromatics have been reported from similar studies of $CHCl_3$,[52] the chlorinated methanes[48] and chloromethane mixtures.[47]

In a recently published study,[48] product distributions from the oxidative pyrolysis of CH_3Cl, CH_2Cl_2, $CHCl_3$, and CCl_4 have been determined (cf. Figures 2.6-2.9). The parent decomposition profiles of CH_3Cl, CH_2Cl_2 and $CHCl_3$ were accurately modeled using reaction pathways and kinetic rate parameters shown in Table 2.10. The composition of the radical pool which governs bimolecular destruction pathways was estimated using a pseudo-equilibrium calculational approach.[53]

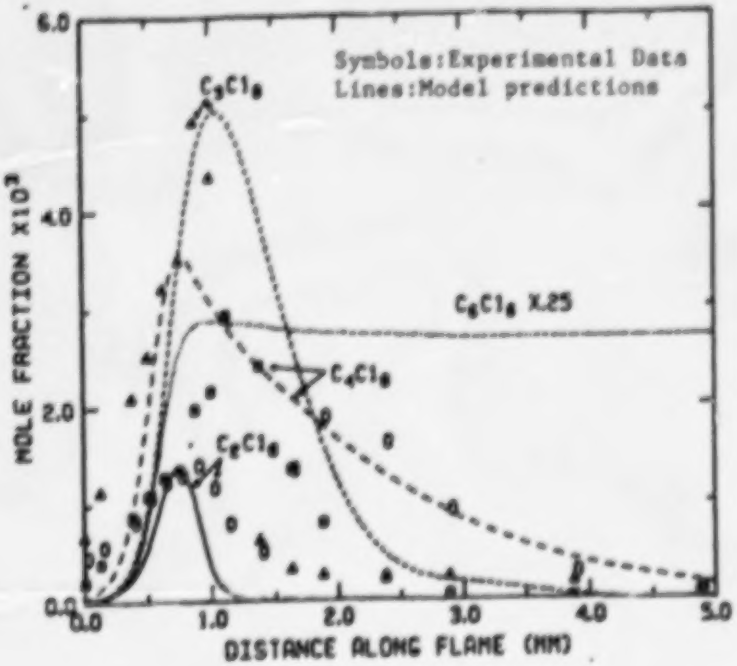


Figure 2.5. Comparison of the experimental data with model predictions for C_2Cl_6, C_3Cl_6, and C_4Cl_6, and the experimentally derived C_6Cl_8 profile.

TABLE 2.9

Chemical Kinetic Mechanism for the Combustion of C_2HCl_3

	reaction[a]	log A	n	E	ΔH_r(298 K)
		C_2 Kinetics			
1	$C_2HCl_3 \rightleftharpoons C_2HCl_2 + Cl$	33.48[b]	-5.88	88.3	78.8
2	$C_2HCl_3 + Cl \rightleftharpoons C_2HCl_4$	32.56	-6.52	55.2	-22.5
3	$C_2HCl_3 \rightleftharpoons C_2Cl_2 + HCl$ (*)	36.03	-3.82	61.8	19.8
4	$C_2HCl_3 \rightleftharpoons C_2HCl + Cl_2$	35.98	-7.08	83.5	52.4
5	$C_2HCl_3 + Cl \rightleftharpoons C_2HCl_2 + Cl_2$	13.50	0	20.0	17.2
6	$C_2HCl_3 + Cl \rightleftharpoons C_2Cl_3 + HCl$ (**)	12.30	0	5.0	-7.3
7	$C_2HCl_3 + O \rightleftharpoons CHOCl + CCl_2$	13.00	0	2.0	-43.2
8	$C_2HCl_3 + OH \rightleftharpoons CHCl_2COCl + H$	11.50	0	-0.9	-15.4
9	$C_2HCl_3 + ClO \rightleftharpoons CHCl_2COCl + Cl$ (*)	11.09	0	2.0	-64.0
10	$C_2HCl_3 + CCl_3 \rightleftharpoons CCl_4 + C_2HCl_2$	11.30	0	8.0	5.8
11	$C_2HCl_3 + CHCl_2 \rightleftharpoons CHCl_3 + C_2HCl_2$	12.40	0	8.0	-3.0
12	$C_2HCl_3 + C_2HCl_4 \rightleftharpoons C_2HCl_2 + C_2HCl_5$	11.00	0	8.0	7.8
13	$C_2Cl_4 + OH \rightleftharpoons CHCl_2COCl + Cl$	12.78	0	2.4	-38.6
14	$C_2Cl_4 + O \rightleftharpoons COCl_2 + CCl_2$	13.00	0	5.0	-54.3
15	$C_2Cl_4 + ClO \rightleftharpoons CCl_3COCl + Cl$	11.00	0	5.0	-61.9
16	$C_2Cl_4 + Cl \rightleftharpoons C_2Cl_5$	38.42	-7.71	8.3	-17.8
17	$C_2Cl_3 + Cl_2 \rightleftharpoons C_2Cl_4 + Cl$ (**)	12.40	0	3.0	-15.8
18	$C_2HCl_5 \rightleftharpoons HCl + C_2Cl_4$	33.22	-5.70	68.1	9.1
19	$C_2HCl_5 \rightleftharpoons Cl + C_2HCl_4$	39.34	-6.14	72.0	68.8
20	$C_2HCl_5 + Cl \rightleftharpoons HCl + C_2Cl_5$	12.30	0	3.3	-8.7
21	$C_2HCl_5 + Cl \rightleftharpoons Cl_2 + C_2HCl_4$	13.00	0	16.6	9.4
22	$C_2Cl_6 \rightleftharpoons Cl_2 + C_2Cl_4$	36.21	-6.50	60.2	28.8
23	$C_2Cl_6 \rightleftharpoons Cl + C_2Cl_5$	36.13	-6.48	74.4	68.5
24	$C_2Cl_6 + Cl \rightleftharpoons Cl_2 + C_2Cl_5$	13.60	0	18.3	9.0
25	$C_2HCl_2 + M \rightleftharpoons C_2HCl + Cl + M$	14.90	0	28.0	36.2
26	$C_2HCl_2 + Cl \rightleftharpoons C_2Cl_2 + HCl$	15.88	-0.97	1.9	-67.3
27	$C_2HCl_2 + Cl \rightleftharpoons C_2HCl + Cl_2$	9.72	1.66	1.1	-24.3
28	$C_2HCl_2 + O_2 \rightleftharpoons CHOCl + COCl$	11.0	0	5.0	-91.0
29	$C_2Cl_3 + Cl \rightleftharpoons C_2Cl_4$	33.65	-7.81	5.7	-75.0
30	$C_2Cl_3 + Cl \rightleftharpoons C_2Cl_2 + Cl_2$	17.72	-1.88	8.1	-32.7
31	$C_2Cl_3 + O_2 \rightleftharpoons COCl_2 + COCl$ (**)	11.50	0	5.0	-100.4
32	$C_2Cl_3 + O_2 \rightleftharpoons C_2Cl_2O + ClO$ (**)	11.30	0	5.0	-38.9
33	$C_2Cl_2O + Cl \rightleftharpoons CO + CCl_3$ (**)	13.00	0	0	-17.4
34	$C_2Cl_2 + O \rightleftharpoons CO + CCl_2$	13.0	0	0	-111.6
35	$C_2Cl_2 + ClO \rightleftharpoons CO + CCl_3$	12.00	0	0	-116.4
36	$C_2HCl_4 + O_2 \rightleftharpoons CHCl_2COCl + ClO$	11.0	0	5.0	-40.3
37	$CHCl_2COCl + Cl \rightleftharpoons CCl_2COCl + HCl$ (*)	13.00	0	5.0	-3.1
38	$CHCl_2COCl + Cl \rightleftharpoons CHCl_2CO + Cl_2$	14.00	0	17.6	17.5
39	$CCl_2COCl \rightleftharpoons CCl_3 + CO$ (*)	12.00	0	5.0	5.6
40	$CHCl_2CO \rightleftharpoons CHCl_2 + CO$	13.30	0	13.5	12.8
41	$C_2HCl_4 + Cl \rightleftharpoons CHCl_2 + CCl_3$	30.79	-1.75	16.5	8.9
42	$C_2Cl_5 + Cl \rightleftharpoons CCl_3 + CCl_3$	27.23	-4.05	13.1	-1.0
43	$C_2Cl_5 + Cl \rightleftharpoons C_2Cl_4 + Cl_2$	27.10	-4.73	8.8	-41.7
44	$C_2Cl_5 + O_2 \rightleftharpoons CCl_3COCl + ClO$	12.00	0	12.0	-44.8
45	$CCl_3COCl + Cl \rightleftharpoons CCl_3CO + Cl_2$	14.00	0	17.6	15.5
46	$CCl_3CO \rightleftharpoons CCl_3 + CO$	13.50	0	8.0	9.6
47	$C_2Cl_2 + O \rightleftharpoons CCl_2 + CO$	13.85	0	0	-70.9
48	$C_2Cl_2 + O_2 \rightleftharpoons COCl + COCl$ (**)	11.00	0	5.0	-49.2
49	$C_2Cl_2 + Cl_2 \rightleftharpoons C_2Cl_4$	38.41	-7.17	40.8	-43.3
50	$C_2Cl_4 + M \rightleftharpoons C_2Cl_3 + Cl + M$ (*)	14.90	0	28.0	36.8
51	$C_2Cl_2 + ClO \rightleftharpoons CO + CCl_3$	11.0	0	0	-72.4
52	$C_2Cl_2 + OH \rightleftharpoons CO + CHCl_2$	12.00	0	0	-81.8
		C_1 Kinetics			
53	$CHCl_3 \rightleftharpoons CHCl_2 + Cl$	27.40	-4.08	79.7	79.7
54	$CHCl_3 + O \rightleftharpoons COCl_2 + HCl$	11.00	0	4.0	-110.8
55	$CHCl_3 + O \rightleftharpoons CCl_3 + OH$	12.46	0	5.0	-4.7
56	$CHCl_3 + Cl \rightleftharpoons CHCl_2 + Cl_2$	14.00	0	21.0	20.2
57	$CHCl_3 + Cl \rightleftharpoons CCl_3 + HCl$ (*)	12.84	0	3.3	-7.8
58	$CCl_4 \rightleftharpoons CCl_3 + Cl$	35.87	-6.88	73.4	70.8
59	$CCl_3 + O \rightleftharpoons CCl_2 + ClO$	10.40	0	3.3	8.0
60	$CCl_3 + O_2 \rightleftharpoons COCl_2 + ClO$ (*)	13.00	0	20.0	-47.7
61	$CCl_3 + O \rightleftharpoons COCl_2 + Cl$	14.00	0	0	-100.8
62	$CCl_3 + Cl_2 \rightleftharpoons CCl_4 + Cl$ (*)	12.40	0	6.0	-11.4
63	$CCl_3 + CCl_3 \rightleftharpoons C_2Cl_6$	38.15	-7.48	6.7	-67.5
64	$CCl_3 + CCl_3 \rightleftharpoons C_2Cl_4 + Cl_2$	26.26	-4.43	9.0	-40.7
65	$CCl_3 + CHCl_2 \rightleftharpoons C_2HCl_5$	34.23	-6.79	6.0	-77.8
66	$CCl_3 + CHCl_2 \rightleftharpoons C_2Cl_4 + HCl$	20.37	-2.45	6.4	-68.7
67	$CHCl_2 + O_2 \rightleftharpoons CHOCl + ClO$	13.90	0	28.0	-41.8
68	$CHCl_2 + O \rightleftharpoons CHOCl + Cl$	14.00	0	0	-96.9
69	$CCl_2 + O_2 \rightleftharpoons ClO + COCl$	13.00	0	1.0	-37.1
70	$CCl_2 + Cl_2 \rightleftharpoons CCl_3 + Cl$	12.70	0	3.0	-7.8
71	$CHOCl + M \rightleftharpoons CO + HCl + M$	17.00	0	40.0	-8.3
72	$CHOCl + Cl \rightleftharpoons COCl + HCl$	13.30	0	3.0	-15.4

TABLE 2.9 Chemical Kinetic Mechanism for the Combustion of C_2HCl_3 (continued)

73	$CCl_2 + C_2Cl_2 = C_3Cl_4$ (*)	11.50	0	5.3	-32.8
74	$C_3HCl_3 + Cl = C_3Cl_3 + HCl$ (*)	12.70	0	5.0	-12.2
75	$C_3Cl_4 + Cl = C_3Cl_3 + Cl_2$ (*)	13.50	0	20.0	19.5
76	$CCl_2 + C_2HCl_2 = C_3HCl_4$ (*)	11.78	0	5.3	-22.6
77	$C_3HCl_4 + O_2 = C_3Cl_4 + HO_2$	12.00	0	5.0	-17.4
78	$C_3HCl_4 = C_3HCl_3 + Cl$	13.00	0	22.0	21.8
79	$C_3Cl_5 = C_3Cl_4 + Cl$ (*)	13.00	0	18.6	17.5
80	$CCl_2 + C_3Cl_3 = C_4Cl_5$	11.50	0	4.3	-27.3
81	$C_2Cl_2 + C_2Cl_3 = C_4Cl_5$ (*)	11.80	0	4.2	-40.7
82	$C_2Cl_3 + C_2Cl_2 = C_4Cl_5$ (*)	12.30	0	4.0	-39.4
83	$C_4Cl_5 = C_4Cl_4 + Cl$ (*)	10.00	0	0	-19.8
84	$C_4Cl_4 + Cl = C_4Cl_3 + Cl_2$ (*)	13.70	0	20.0	17.7
85	$C_4HCl_3 + Cl = C_4Cl_3 + HCl$ (*)	13.30	0	3.0	-12.2
86	$C_2Cl_3 + C_2Cl_2 = C_4Cl_5$	11.28	0	4.1	-32.7
87	$C_4Cl_5 = C_4Cl_4 + Cl$	13.00	0	18.0	16.6
88	$C_4HCl_4 + O_2 = C_4Cl_4 + HO_2$	13.00	0	5.0	-22.5
89	$C_2Cl_2 + C_2HCl_2 = C_4HCl_4$ (*)	11.70	0	3.0	-23.9
90	$C_4HCl_4 = C_4HCl_3 + Cl$ (*)	13.00	0	16.0	14.9
91	$C_4Cl_4 + C_2Cl_2 = C_6Cl_5 + Cl$ (*)	11.70	0	1.0	-15.4
92	$C_6Cl_6 = C_6Cl_4 + Cl_2$ (*)	10.00	0	0	0.9
	CO and H_2 Kinetics				
93	$CO + O + M = CO_2 + M$	13.73	0	-4.5	-128.0
94	$CO + OH = CO_2 + H$	6.64	1.5	-0.7	-23.6
95	$CO + O_2 = CO_2 + O$ (*)	13.30	0	41.0	-7.2
96	$CO + HO_2 = CO_2 + OH$	14.18	0	23.6	-58.1
97	$H_2 + O_2 = OH + OH$	13.33	0	48.1	18.0
98	$OH + H_2 = H_2O + H$	8.00	1.6	3.3	-15.3
99	$H + O_2 = OH + O$	17.08	-0.91	16.5	16.4
100	$O + H_2 = OH + H$	7.18	2.0	7.6	1.9
101	$H + O_2 + M = HO_2 + M$	17.85	-0.8	0	-53.5
102	$OH + HO_2 = H_2O + O_2$	13.30	0	0	-68.1
103	$H + HO_2 = OH + OH$	14.39	0	1.0	-34.5
104	$O + HO_2 = O_2 + OH$	13.30	0	0	-51.6
105	$OH + OH = O + H_2O$	9.18	1.14	0	-17.1
106	$H + H + M = H_2 + M$	18.00	-1.0	0	-106.3
107	$H + H + H_2 = H_2 + H_2$	16.98	-0.6	0	-108.5
108	$H + H + H_2O = H_2 + H_2O$	19.78	-1.28	0	-108.1
109	$H + H + CO_2 = H_2 + CO_2$	20.74	-2.0	0	-108.3
110	$H + OH + M = H_2O + M$	22.30	-2.0	0	-121.6
111	$H + O + M = OH + M$	16.79	-0.6	0	-104.6
112	$H + HO_2 = H_2 + O_2$	13.40	0	0.7	-53.8
113	$ClO + CO = CO_2 + Cl$ (*)	11.78	0	7.4	-63.3
114	$COCl + M = CO + Cl + M$ (**)	14.30	0	6.5	7.1
115	$COCl + H = CO + HCl$	14.00	0	0	-98.4
116	$COCl + OH = CO + HOCl$	14.00	0	0	-50.5
117	$COCl + O = CO + ClO$	14.00	0	0	-58.7
118	$COCl + O = CO_2 + Cl$	13.00	0	0	-120.9
119	$COCl + O_2 = CO_2 + ClO$	10.90	0	3.3	-65.9
120	$COCl + Cl = CO + Cl_2$ (*)	13.10	0.5	0.8	-52.4
121	$Cl_2 + M = Cl + Cl + M$	13.37	0	47.0	59.3
122	$HCl + M = H + Cl + M$	13.44	0	81.6	106.6
123	$HCl + H = H_2 + Cl$	12.90	0	3.4	-0.8
124	$H + Cl_2 = HCl + Cl$	13.93	0	1.2	-46.0
125	$O + HCl = OH + Cl$	13.50	0	6.7	1.0
126	$OH + HCl = Cl + H_2O$	12.38	0	1.0	-16.1
127	$O + Cl_2 = ClO + Cl$	13.10	0	2.8	-6.4
128	$O + ClO = Cl + O_2$	13.78	0	0.4	-56.0
129	$Cl + HO_2 = HCl + O_2$	12.90	0	0	-52.0
130	$Cl + HO_2 = OH + ClO$	13.80	0	1.7	4.1
131	$ClO + H_2 = HOCl + H$	13.00	0	13.5	10.2
132	$H + HOCl = HCl + OH$	13.00	0	1.0	-47.9
133	$Cl + HOCl = HCl + ClO$	13.00	0	2.0	-9.3
134	$Cl + HOCl = Cl_2 + OH$	13.10	0	6.0	-1.9
135	$O + HOCl = OH + ClO$	13.70	0	1.5	-8.3
136	$OH + HOCl = H_2O + ClO$	12.38	0	3.0	-25.4
137	$HOCl + M = OH + Cl + M$	18.00	0	56.0	57.6
138	$ClOO + CO = CO_2 + ClO$	14.00	0	20.0	-66.4
139	$ClOO + M = Cl + O_2 + M$	15.00	0	7.0	6.6
140	$Cl + ClOO = Cl_2 + O_2$	13.90	0	0.5	-53.9
141	$Cl + ClOO = ClO + ClO$	12.70	0	0.6	-4.3
142	$O + ClOO = ClO + O_2$	13.50	0	0.5	-59.3
143	$COCl_2 + M = COCl + Cl + M$	16.00	0	76.0	78.0
144	$COCl_2 + M = CO + Cl_2 + M$	16.09	0	90.0	25.8
145	$COCl_2 + Cl = COCl + Cl_2$ (**)	13.50	0.5	20.0	18.5

TABLE 2.9 Chemical Kinetic Mechanism for the Combustion of C_2HCl_3 (continued)

73	$CCl_3 + C_2Cl_3 \rightleftharpoons C_3Cl_6$ (*)	11.50	0	5.3	-32.6
74	$C_3HCl_6 + Cl \rightleftharpoons C_3Cl_6 + HCl$ (*)	12.70	0	5.0	-12.2
75	$C_3Cl_6 + Cl \rightleftharpoons C_3Cl_5 + Cl_2$ (*)	13.50	0	20.0	19.5
76	$CCl_3 + C_2HCl_3 \rightleftharpoons C_3HCl_6$ (*)	11.76	0	5.3	-22.6
77	$C_3HCl_6 + O_2 \rightleftharpoons C_3Cl_6 + HO_2$	12.00	0	5.0	-17.4
78	$C_3HCl_6 \rightleftharpoons C_3HCl_5 + Cl$	13.00	0	22.0	21.8
79	$C_3Cl_7 \rightleftharpoons C_3Cl_6 + Cl$ (*)	13.00	0	18.6	17.5
80	$CCl_3 + C_2Cl_4 \rightleftharpoons C_3Cl_7$	11.50	0	4.3	-27.3
81	$C_2Cl_3 + C_2Cl_3 \rightleftharpoons C_4Cl_6$ (*)	11.80	0	4.2	-40.7
82	$C_2Cl_3 + C_4Cl_4 \rightleftharpoons C_6Cl_7$ (*)	12.30	0	4.0	-39.4
83	$C_6Cl_7 \rightarrow C_6Cl_6 + Cl$ (*)	10.00	0	0	-19.6
84	$C_4Cl_6 + Cl \rightleftharpoons C_4Cl_5 + Cl_2$ (*)	12.70	0	20.0	17.7
85	$C_4HCl_6 + Cl \rightleftharpoons C_4Cl_6 + HCl$ (*)	13.30	0	3.0	-12.2
86	$C_2Cl_3 + C_2Cl_4 \rightleftharpoons C_4Cl_7$	11.28	0	4.1	-32.7
87	$C_4Cl_7 \rightleftharpoons C_4Cl_6 + Cl$	13.00	0	18.0	16.6
88	$C_4HCl_6 + O_2 \rightleftharpoons C_4Cl_6 + HO_2$	12.00	0	5.0	-22.5
89	$C_2Cl_3 + C_2HCl_3 \rightleftharpoons C_4HCl_6$ (*)	11.70	0	3.0	-23.9
90	$C_4HCl_6 \rightleftharpoons C_4HCl_5 + Cl$ (*)	13.00	0	16.0	14.9
91	$C_4Cl_6 + C_2Cl_3 \rightleftharpoons C_6Cl_8 + Cl$ (*)	11.70	0	1.0	-15.4
92	$C_6Cl_8 \rightarrow C_6Cl_6 + Cl_2$ (*)	10.00	0	0	0.9
		CO and H_2 Kinetics			
93	$CO + O + M \rightleftharpoons CO_2 + M$	13.72	0	-4.5	-128.0
94	$CO + OH \rightleftharpoons CO_2 + H$	6.64	1.5	-0.7	-23.6
95	$CO + O_2 \rightleftharpoons CO_2 + O$ (*)	13.20	0	41.0	-7.2
96	$CO + HO_2 \rightleftharpoons CO_2 + OH$	14.18	0	23.6	-58.1
97	$H_2 + O_2 \rightleftharpoons OH + OH$	13.23	0	48.1	18.3
98	$OH + H_2 \rightleftharpoons H_2O + H$	8.00	1.6	3.3	-15.3
99	$H + O_2 \rightleftharpoons OH + O$	17.08	-0.91	16.5	16.4
100	$O + H_2 \rightleftharpoons OH + H$	7.18	2.0	7.6	1.9
101	$H + O_2 + M \rightleftharpoons HO_2 + M$	17.85	-0.8	0	-53.5
102	$OH + HO_2 \rightleftharpoons H_2O + O_2$	13.30	0	0	-68.1
103	$H + HO_2 \rightleftharpoons OH + OH$	14.20	0	1.0	-34.5
104	$O + HO_2 \rightleftharpoons O_2 + OH$	13.30	0	0	-51.0
105	$OH + OH \rightleftharpoons O + H_2O$	9.18	1.14	0	-17.1
106	$H + H + M \rightleftharpoons H_2 + M$	18.00	-1.0	0	-106.3
107	$H + H + H_2 \rightleftharpoons H_2\ p\ H_2$	16.96	-0.6	0	-106.3
108	$H + H + H_2O \rightleftharpoons H_2 + H_2O$	19.78	-1.25	0	-106.3
109	$H + H + CO_2 \rightleftharpoons H_2 + CO_2$	20.74	-2.0	0	-106.3
110	$H + OH + M \rightleftharpoons H_2O + M$	22.20	-2.0	0	-121.6
111	$H + O + M \rightleftharpoons OH + M$	16.79	-0.6	0	-104.5
112	$H + HO_2 \rightleftharpoons H_2 + O_2$	13.40	0	0.7	-52.8
113	$ClO + CO \rightleftharpoons CO_2 + Cl$ (*)	11.78	0	7.4	-62.2
114	$COCl + M \rightleftharpoons CO + Cl + M$ (**)	14.30	0	6.5	7.1
115	$COCl + H \rightleftharpoons CO + HCl$	14.00	0	0	-98.4
116	$COCl + OH \rightleftharpoons CO + HOCl$	14.00	0	0	-50.5
117	$COCl + O \rightleftharpoons CO + ClO$	14.00	0	0	-58.7
118	$COCl + O \rightleftharpoons CO_2 + Cl$	13.00	0	0	-120.9
119	$COCl + O_2 \rightleftharpoons CO_2 + ClO$	10.90	0	3.3	-65.9
120	$COCl + CL \rightleftharpoons CO + Cl_2$ (*)	13.10	0.5	0.5	-52.4
121	$Cl_2 + M \rightleftharpoons Cl + Cl + M$	13.37	0	47.0	59.5
122	$HCl + M \rightleftharpoons H + Cl + M$	13.44	0	81.8	105.5
123	$HCl + H \rightleftharpoons H_2 + Cl$	12.90	0	3.4	-0.8
124	$H + Cl_2 \rightleftharpoons HCl + Cl$	13.93	0	1.2	-46.0
125	$O + HCl \rightleftharpoons OH + Cl$	13.50	0	6.7	1.0
126	$OH + HCl \rightleftharpoons Cl + H_2O$	12.35	0	1.0	-16.1
127	$O + Cl_2 \rightleftharpoons ClO + Cl$	13.10	0	2.8	-6.4
128	$O + ClO \rightleftharpoons Cl + O_2$	13.76	0	0.4	-55.0
129	$Cl + HO_2 \rightleftharpoons HCl + O_2$	12.90	0	0	-52.0
130	$Cl + HO_2 \rightleftharpoons OH + ClO$	13.80	0	1.7	4.1
131	$ClO + H_2 \rightleftharpoons HOCl + H$	13.00	0	13.5	10.2
132	$H + HOCl \rightleftharpoons HCl + OH$	13.00	0	1.0	-47.9
133	$Cl + HOCl \rightleftharpoons HCl + ClO$	13.00	0	2.0	-9.3
134	$Cl + HOCl \rightleftharpoons Cl_2 + OH$	13.10	0	6.0	-1.9
135	$O + HOCl \rightleftharpoons OH + ClO$	13.70	0	1.5	-8.3
136	$OH + HOCl \rightleftharpoons H_2O + ClO$	12.26	0	3.0	-25.4
137	$HOCl + M \rightleftharpoons OH + Cl + M$	18.00	0	56.0	57.6
138	$ClOO + CO \rightleftharpoons CO_2 + ClO$	14.00	0	20.0	-66.4
139	$ClOO + M \rightleftharpoons Cl + O_2 + M$	15.00	0	7.0	6.6
140	$Cl + ClOO \rightleftharpoons Cl_2 + O_2$	13.90	0	0.5	-52.9
141	$Cl + ClOO \rightleftharpoons ClO + ClO$	12.70	0	0.5	-4.2
142	$O + ClOO \rightleftharpoons ClO + O_2$	13.50	0	0.5	-59.2
143	$COCl_2 + M \rightleftharpoons COCl + Cl + M$	16.00	0	76.0	78.0
144	$COCl_2 + M \rightleftharpoons CO + Cl_2 + M$	16.00	0	50.0	25.6
145	$COCl_2 + Cl \rightleftharpoons COCl + Cl_2$ (**)	13.50	0.5	20.0	18.5

TABLE 2.9. Chemical Kinetic Mechanism for the Combustion of C_2HCl_3 (continued)

	reaction[b,c]	log *A*	*n*	*E*	ΔH_r(298 K)
146	$COCl_2 + OH \rightleftharpoons COCl + HOCl$	12.00	0	10.0	20.4
147	$COCl_2 + H \rightleftharpoons COCl + HCl$	13.00	0	2.0	-27.5

[a] $k = AT^n \exp(-E/RT)$, in cm, kcal, s, and mole units. [b] Chaperon efficiencies of third-body M: O_2 = 0.35, H_2O = 6.5, CO_2 = 1.47, CO = 0.74, H_2 = 1.0, N_2 = 0.44. [c] **, most sensitive reactions; *, second most sensitive reactions. [d] Significant figures are for consistency, not to indicate an established accuracy of these parameters.

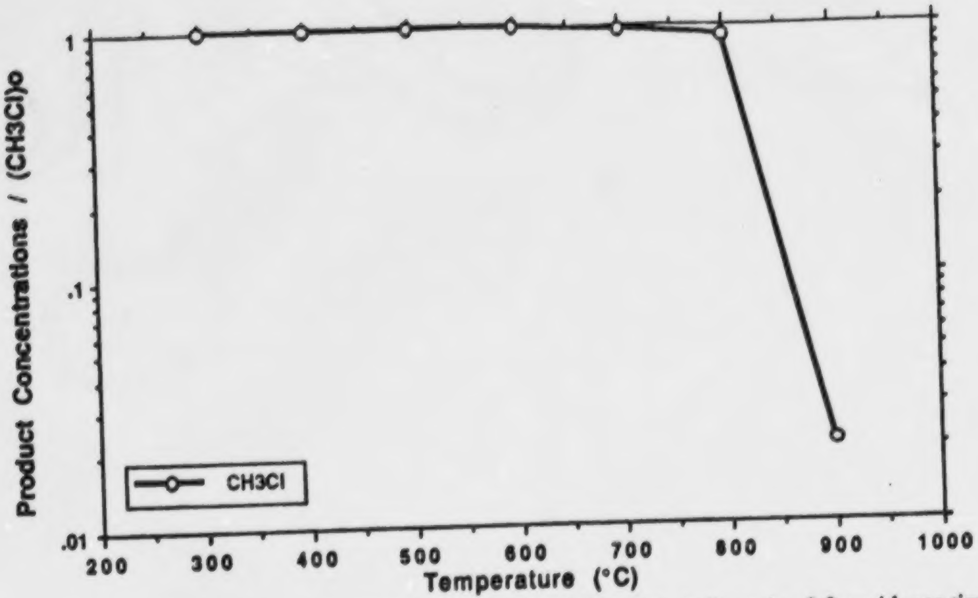


Figure 2.6. Atmospheric pressure oxidative pyrolysis of CH_3Cl in helium. $\phi = 3.0$, residence time = 2.0 s, $[CH_3Cl]_0 = 2.3 \times 10^{-5}$ moles/L. Organic products were not detectable at levels greater than $0.01[CH_3Cl]_0$.

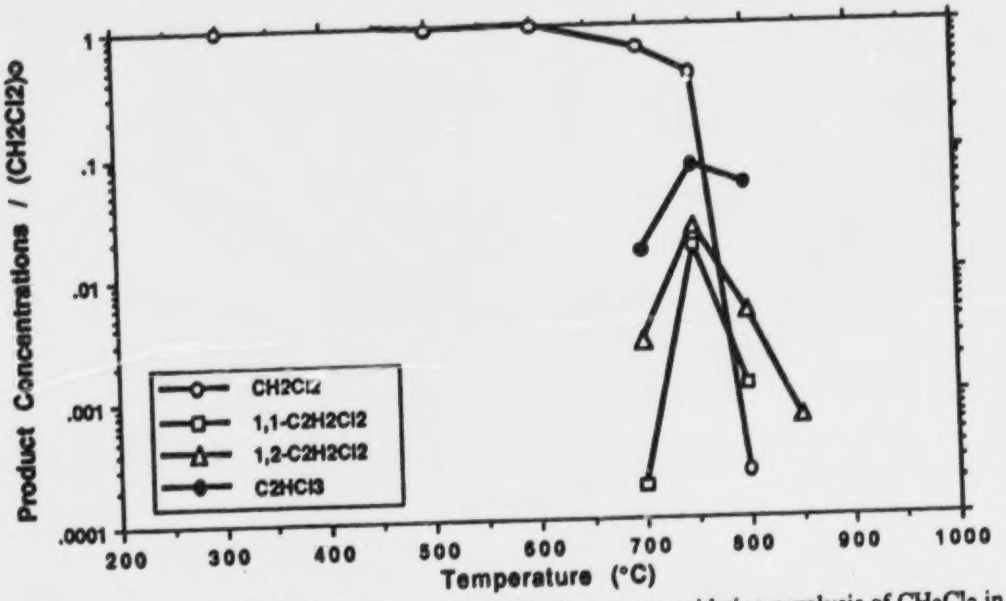


Figure 2.7. Product distributions from the atmospheric pressure oxidative pyrolysis of CH_2Cl_2 in helium. $\phi = 3.0$, residence time = 2.0 s, $[CH_2Cl_2]_0 = 2.3 \times 10^{-5}$ moles/L.

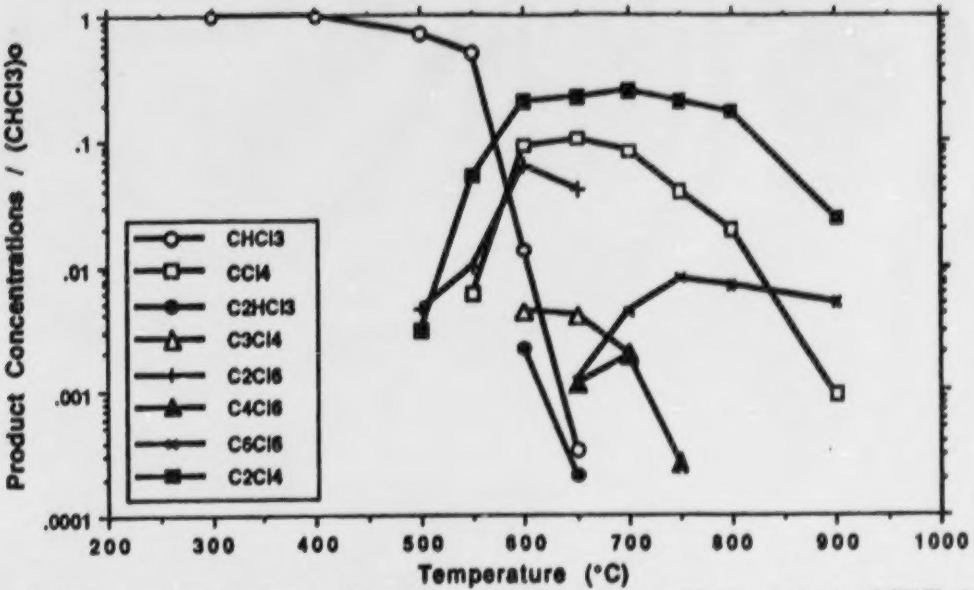


Figure 2.8. Product distributions from the atmospheric pressure oxidative pyrolysis of $CHCl_3$ in helium. $\phi = 3.0$, residence time = 2.0 s, $[CHCl_3]_0 = 2.3 \times 10^{-5}$ moles/L.

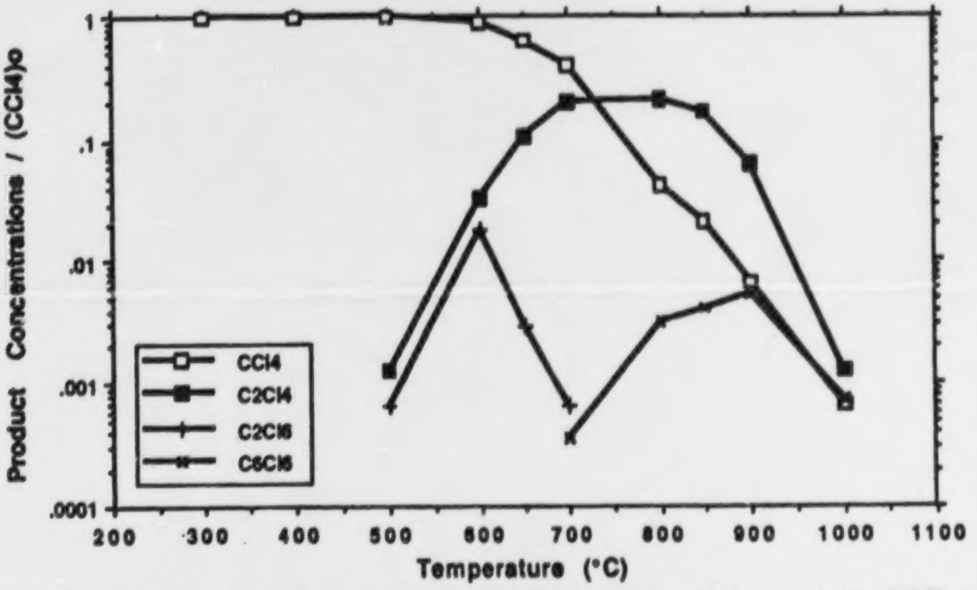


Figure 2.9. Product distributions from the atmospheric pressure oxidative pyrolysis of CCl_4 in helium. $\phi = 3.0$, residence time = 2.0 s, $[CCl_4]_0 = 2.3 \times 10^{-5}$ moles/L.

TABLE 2.10

Chlorinated Methane Decomposition Rate Parameters[a]

Compound	C-Cl Fission[b] s^{-1}	HCl Elimination[c] s^{-1}	H Abstraction by Cl l/mol-s
CH_3Cl	15.7 - 82.5/θ	14.1 - 89.6/θ	10.5 - 3.3/θ
CH_2Cl_2	16.6 - 79.7/θ	14.1 - 72.3/θ	10.4 - 3.0/θ
$CHCl_3$	16.3 - 77.3/θ	14.3 - 54.5/θ	9.8 - 3.3/θ
CCl_4	16.0 - 70.0/θ	N/A	N/A

Notes:

a. Rate constants are calculated at 300 K in the form log k = log A - Ea/θ where θ = 2.303RT.

b. Rate constants are expressed as high-pressure limit values; A factors calculated from transition state theory ; $Ea = \Delta H_{R,300} - 0.5RT$ assuming zero energy barrier for reverse reaction.

c. Rate constants are expressed as high-pressure limit values; except where noted, A factors calculated from transition state theory ; $Ea = \Delta H_{R,300} - 0.5RT$ assuming 5 kcal/mole energy barrier for reverse reaction.

Transition state calculations indicated that three-center concerted HCl elimination is the principal decomposition mechanism for $CHCl_3$, accounting for nearly all of the decay at the 99% decomposition level (600°C). The formation of all observed species containing up to 2 carbon atoms was reasonably modeled using the simple reaction scheme shown in Table 2.11. HCl elimination and C-Cl bond rupture represented approximately 95% and 3% of the destruction of CH_2Cl_2 at the 99% decomposition level (780°C), respectively. Due to the relative strength of the C-Cl bond in CH_3Cl as compared to the other chloromethanes, H atom abstraction by Cl atoms (57.5%) dominates the CH_3Cl decay at the 99% DE level (910°C); unimolecular C-Cl bond rupture and concerted HCl elimination contribute 42% and <1%, respectively. The thermal decomposition of CCl_4 could not be accurately modeled by initiation processes involving C-Cl bond fission and Cl atom abstraction reactions. The experimental data suggested that the endothermicity of Cl abstraction resulted in the suppression of radical chains.

The most noteworthy aspect of these studies was the relatively high yields of the chlorinated aromatic, C_6Cl_6, produced from the oxidative pyrolysis of $CHCl_3$ and CCl_4. A simple mechanism was proposed involving the formation of key intermediate species C_2HCl_3, C_2Cl_4 and C_2Cl_2 which is consistent with the observed product distribution.[47,48] The unchlorinated homologs of these species have also been proposed as key intermediates in soot formation from hydrocarbons and CH_3Cl.[51,54-56] However, based on the absence of production of chlorinated aromatics from CH_3Cl and CH_2Cl_2, it appears that chlorine facilitates condensation reactions resulting in the formation of higher molecular weight chlorinated species.

Recent hydrocarbon molecular growth mechanisms propose both chemically activated, single-step "direct" addition reactions (H elimination from an energy-rich adduct) and "indirect" routes involving sequential addition and H atom elimination reactions.[54-56] "Direct"[49,57] and "indirect"[47,48] Cl displacement reactions have also been proposed as key steps in the condensation of CHCs. These mechanisms are qualitatively consistent with the high yields of chlorinated aromatics for the more chlorinated CHCs. Furthermore, highly chlorinated species are more resistant to oxidative degradation and

Table 2.11

Low Temperature (<800°C), Oxygen-Free, $CHCl_3$ Elementary Kinetic Mechanism[1]

Reaction	Forward Reaction A	n	Ea	Reverse Reaction A	n	Ea	Ref.[2]
1. $CHCl_3$ -- CCl_2 + HCl	2.0E14	0	54.5	3.2E10	0	0.0	a
2. $CHCl_3$ + CCl_2 -> $CHCl_2$ + CCl_3	3.0E8	0	12.0				b
3. $CHCl_3$ + CCl_3 — CCl_4 + $CHCl_2$	3.0E8	0	8.0	4.0E8	0	5.0	b
4. CCl_4 + M — CCl_3 + Cl + M	1.0E16	0	70.3	6.3E10	0	0.0	b
5. $CHCl_3$ + Cl — CCl_3 + HCl	6.3E9	0	3.3	4.0E8	0	11.3	c
6. C_2Cl_6 -- $2CCl_3$	2.5E16	0	69.5	5.0E9	0	0.0	b
7. C_2Cl_6 -- C_2Cl_5 + Cl	2.0E17	0	68.9	3.2E10	0	0.0	b
8. C_2Cl_6 + CCl_3 — C_2Cl_5 + CCl_4	5.0E8	0	5.0	3.0E8	0	5.0	b
9. C_2Cl_5 -- C_2Cl_4 + Cl	2.5E13	0	15.5	1.5E9	0	0.0	d
10. $2CCl_2$ + M -- C_2Cl_4 + M	3.2E10	0	0.0	1.0E16	0	96.4	b
11. 2Cl + M -- Cl_2 + M	7.9E11	0	0.0	3.1E14	0	56.0	c
12. $CHCl_2$ + CCl_3 -- C_2HCl_5	3.2E10	0	0.0	4.0E17	0	76.0	b
13. C_2HCl_5 -- C_2Cl_4 + HCl	1.3E14	0	59.7	1.0E8	0	45.0	d
14. CCl_3 + Cl_2 — CCl_4 + Cl	2.0E10	0	5.3	1.0E11	0	20.0	e
15. $2CHCl_2$ -- $C_2H_2Cl_4$	3.2E10	0	0.0	5.0E17	0	76.3	b
16. C_2Cl_5 -- CCl_2 + CCl_3	1.0E17	0	57.0	1.0E10	0	0.0	b
17. C_2Cl_4 + M — C_2Cl_3 + Cl + M	4.5E14	0	80.0	6.9E4	1.2	-5.3	f

Footnote:

[1] Units of Arrhenius parameters are liters, mole, s, kcal.

[2] Bibliographic sources.

[a] Schug, K.P., Wagner, H. Gg., and Zabel, F. (1979) Ber. Bunsenges. Phys. Chem. 83, 167.

[b] Estimated by Thermochemical Transition State Theory, reference 29.

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[e] Kerr, J.A. and Moss, S.J., eds. (1981) "Handbook of Bimolecular and Termolecular Gas Reactions, Vol. II," CRC Press, Boca Raton, FL.

[f] Zabel, F. (1974) Ber. Bunsenges. Phys. Chem. 78, 232.

therefore more available for condensation-type reactions. These observations have led to a recently published study of pyrolysis reactions of C_2Cl_4 which, based on the previously discussed reports, seems to be a direct and important precursor in the formation of chlorinated aromatic species.[49]

Products and yields from the pyrolysis of C_2Cl_4 are displayed in Figure 2.10. Molecular chlorine (Cl_2) was the major product observed at all temperatures. The remaining reaction intermediates included low yield ($<0.1\%$) unstable C_1 - C_4 chlorocarbons, very low yield ($< 0.05\%$) stable chlorinated aromatic species and higher yield ($> 1\%$) highly stable chlorinated aromatic species. Dichloroacetylene was not observed as a reaction intermediate; however, it has been observed in the thermal decomposition of $CHCl_3$[52] and fuel-rich combustion of C_2HCl_3. Its conspicuous absence in C_2Cl_4 pyrolysis is thus attributed to rapid addition reactions after its initial formation.

The most noteworthy aspect of this study was once again the observation of relatively high yields of stable chlorinated aromatic species. Chlorine atom displacement reactions involving perchlorinated acetylenic (and olefinic) radical attack on perchlorinated olefins and acetylenes are proposed as key steps in formation of chlorinated aromatics. This hypothesis is based on consideration of observed product distributions and estimates of the elementary reaction kinetic parameters of hypothetical pathways. The following paragraphs discuss potential pathways leading to the formation of chlorinated aromatics from C_2Cl_4.

Discarding C_3Cl_6 as the product of a side reaction which does not lead to molecular growth, an analysis of the product distribution indicates that C_4Cl_6 is the first key intermediate. Two pathways are plausible for the formation of C_4Cl_6, one involving trichlorovinyl (C_2Cl_3) radical addition to C_2Cl_2 and the second involving C_2Cl_3 addition to C_2Cl_4 (cf. Figure 2.11). The C_2Cl_2 pathway requires the unfavorable addition of C_2Cl_3 to C_2Cl_2, followed by scavenging of Cl by n-C_4Cl_5. The C_2Cl_4 pathway produces C_4Cl_6 via a chemically activated intermediate (n-C_4Cl_7). To compare the relative rates of these reactions at elevated temperatures, transition state and QRRK calculations have been performed.[58] The overall scheme and notation for the

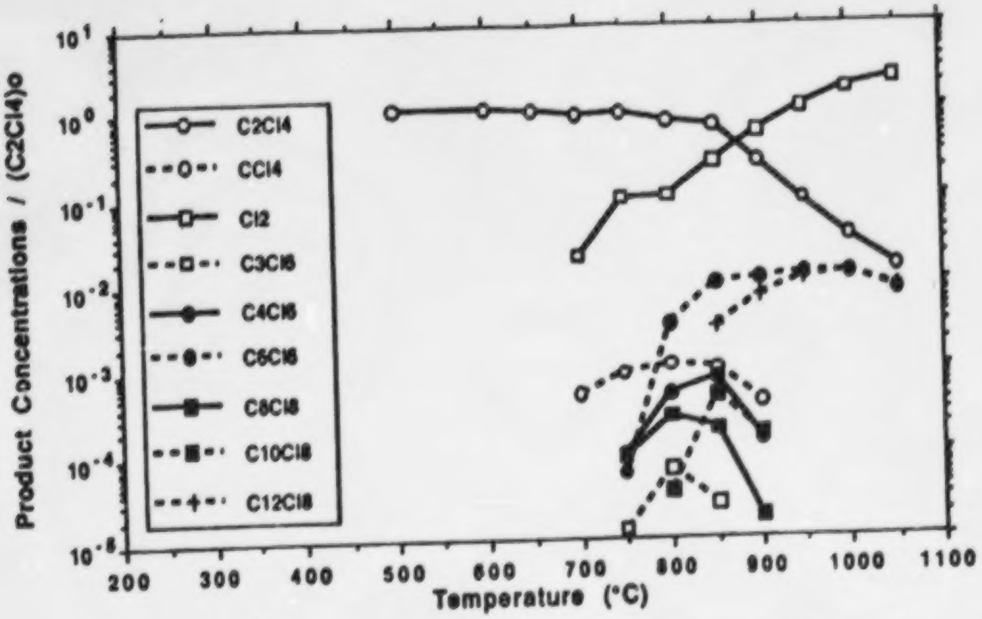


Figure 2.10. Product distributions from the atmospheric pressure pyrolysis of C_2Cl_4 in helium. Residence time = 2.0 s, $[C_2Cl_4]_0 = 5.7 \times 10^{-4}$ moles/L.

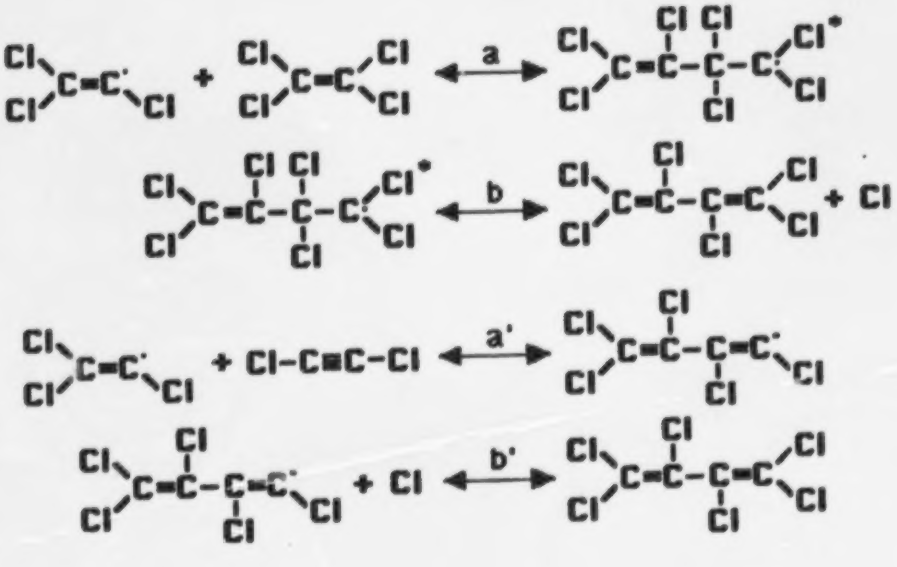


Figure 2.11 Plausible C_4Cl_6 formation pathways. Rxns a and b designate the olefinic pathway, rxns a' and b' designate the acetylenic pathway.

reaction is depicted in Figure 2.12. The results (cf. Figure 2.13) indicate that although the initial step for the chlorocarbon case is slower than the hydrocarbon case, C_4Cl_6 formation is faster than C_4H_6 formation at all temperatures. This is due to the weaker C-Cl bond (85 kcal/mole vs 108 kcal/mole C-H bond in C_2H_4) which results in a rapid rate of Cl versus H displacement once the chemically activated adduct is formed.

Pathways to formation of C_6Cl_6 can be envisioned that also involve acetylenic as well as olefinic species (cf. Figure 2.14). Reaction of n-C_4Cl_5 with C_2Cl_2 can "directly" form C_6Cl_6 by isomerization of the chemically activated adduct (n-C_6Cl_7) ---> c-C_6Cl_7) followed by Cl elimination. n-C_4Cl_5 addition to C_2Cl_4 can also produce C_6Cl_6 through a n-C_6Cl_9 intermediate. However, this pathway requires the elimination of Cl atoms in three sequential steps. Even more complex acetylenic and olefinic pathways may be devised that result in formation of higher molecular weight aromatic species observed in the study of C_2Cl_4 pyrolysis (cf. Figure 2.15).

Using the available data for C_2Cl_4 pyrolysis, one cannot as yet clearly distinguish between the following condensation pathways: 1) side reactions of C_2Cl_2 polymerization, 2) other condensation reactions involving C_2Cl_2, and 3) purely olefinic condensation pathways. Yields of C_6Cl_6 from C_2Cl_4 were less than observed from $CHCl_3$. This suggests an additional reactive species may be involved in the $CHCl_3$ molecular growth pathways, viz., C_2Cl_2, which was an observed product from the pyrolysis of $CHCl_3$. Since C_2Cl_4 should produce C_2Cl_2 as efficiently as $CHCl_3$, it would appear that the higher reaction temperature required for pyrolysis of C_2Cl_4 versus $CHCl_3$ (~800°C versus 600°C) is responsible for its rapid disappearance.

In the absence of C_2Cl_2, relatively fast reactions involving displacement of Cl from olefinic radicals can still result in the moderate buildup of higher molecular weight chlorinated species. Although ethene and substituted ethenes were formed from the thermal degradation of CH_3Cl and CH_2Cl_2, yields of aromatics were low versus $CHCl_3$. This further suggests that C_2Cl_2 may be an important intermediate in molecular growth pathways. The yield of aromatic species from CCl_4 is intermediate between CH_3Cl (or CH_2Cl_2) and $CHCl_3$. This may be due to the fast buffer reaction of Cl

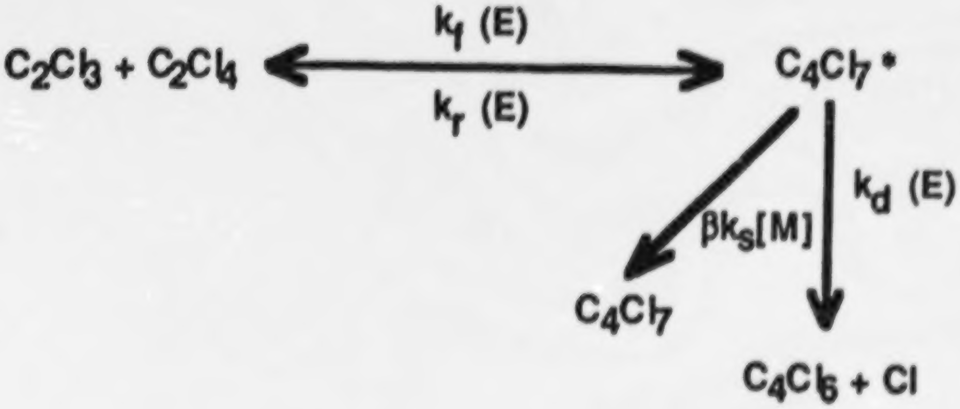

$C_2Cl_3 + C_2Cl_4$
k_f (E)
k_r (E)
C_4Cl_7*
$\beta k_s[M]$
k_d (E)
C_4Cl_7
C_4Cl_6 + Cl

Figure 2.12. Scheme for the formation of C_4Cl_6 (or C_4H_6) from C_2Cl_3 (or C_2H_3) and C_2Cl_4 (or C_2H_4) - Only the CHC reaction is shown.

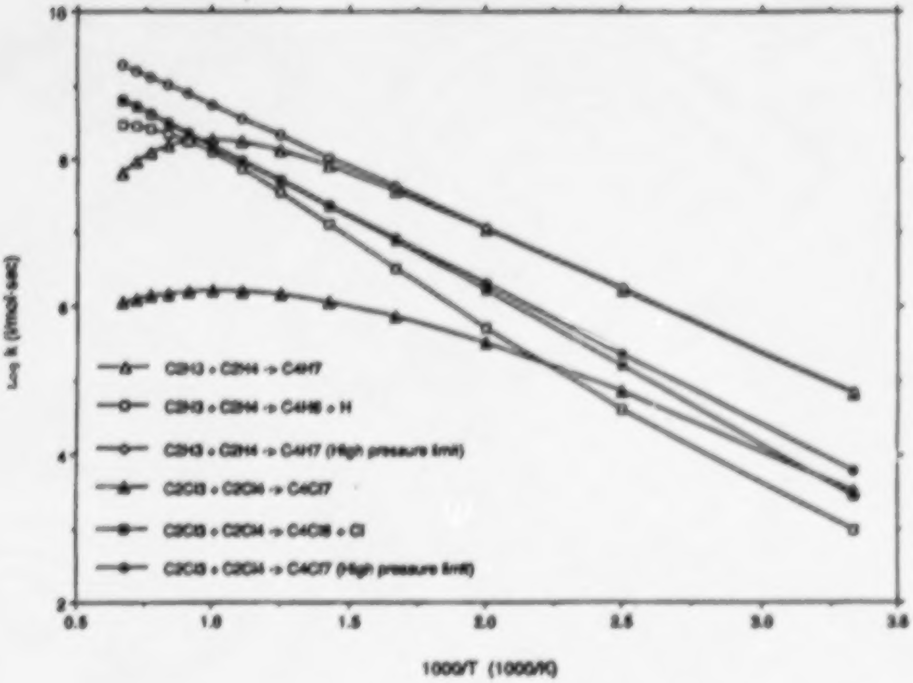


Figure 2.13. QRRK calculation for the C_2Cl_3 + C_2Cl_4 and analogous hydrocarbon reaction. Parameters for the CHC reaction are as follows: log A_f (1000) = 8.6 l mole^{-1}-s^{-1}, E_f = 2.0 kcal/mole^{-1}, log A_d (1000) = 13.8 s^{-1}, E_d = 21.7 kcal mole^{-1}, log A_r (1000) = 13.2 s^{-1}, E_r = 46.6 kcal mole^{-1}, $\nu_{C_4Cl_7}$ = 250 cm^{-1}, $\sigma_{C_4Cl_7}$ = 7.42 Å, and $\epsilon_{C_4Cl_7}$ = 600 k_B. Parameters for the HC reaction are as follows: log A_f = (1000) = 9.2 l mole^{-1}s^{-1}, E_f = 2.0 kcal mole^{-1}, log A_d (100) = 13.5 s^{-1}, E_d = 34.8 kcal mole^{-1}, log A_r (1000) = 13.7 s^{-1}, E_r = 39.5 kcal mole^{-1}, $\nu_{C_4H_7}$ = 1500 cm^{-1}, $\sigma_{C_4H_7}$ = 5.18 Å, and ϵ = 357 k_B. Helium was used as the bath molecule, <ΔE> = 2.9 KJ/mole.

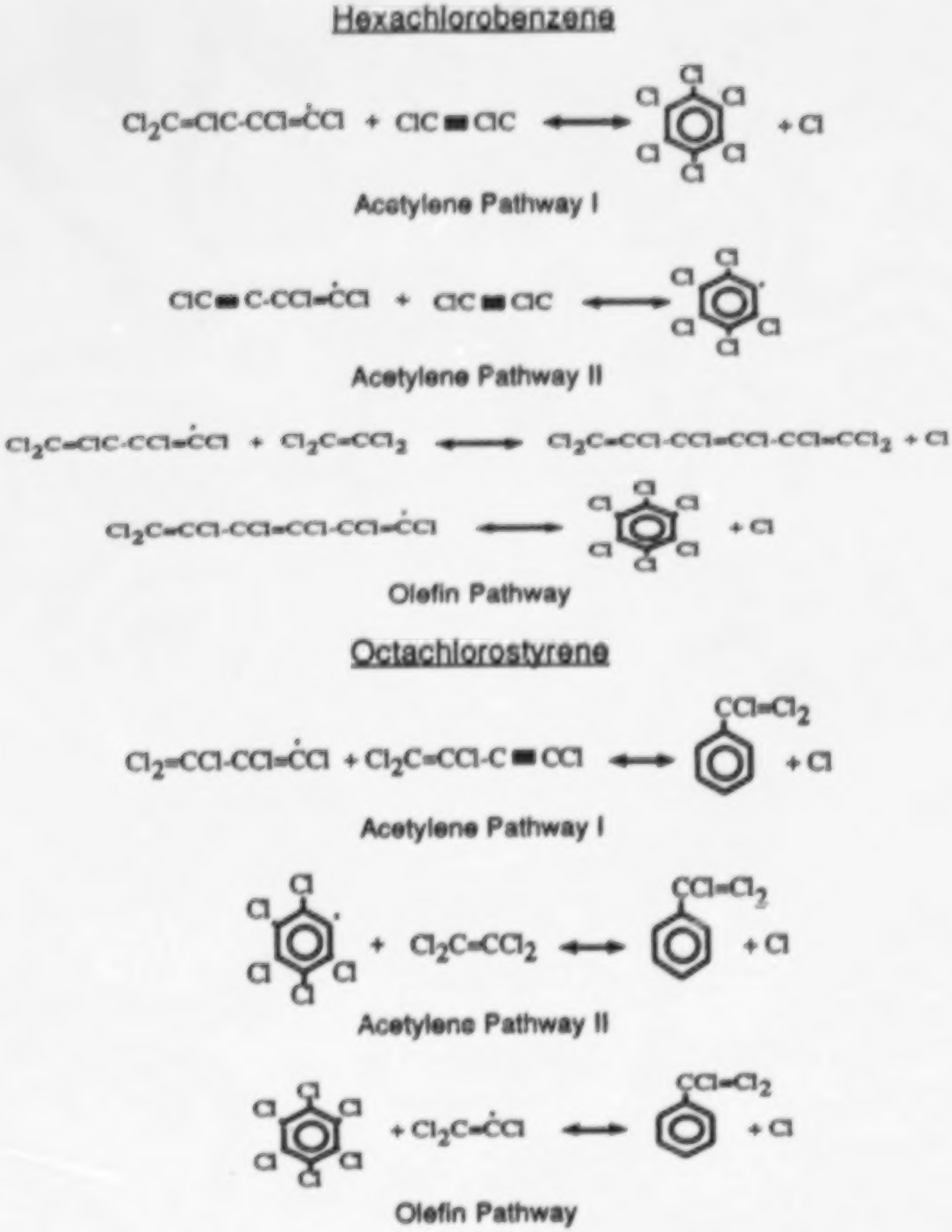
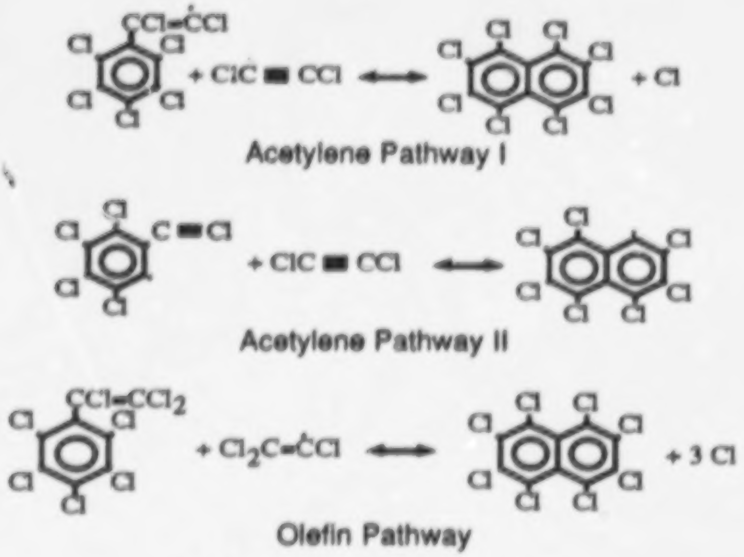

Hexachlorobenzene
Cl2C=ClC-CCl=ĊCl + ClC≡ClC
+Cl
Acetylene Pathway I
ClC≡C-CCl=ĊCl + ClC≡ClC
Acetylene Pathway II
Cl2C=ClC-CCl=ĊCl + Cl2C=CCl2
Cl2C=CCl-CCl=CCl-CCl=CCl2 + Cl
Cl2C=CCl-CCl=CCl-CCl=ĊCl
+ Cl
Olefin Pathway
Octachlorostyrene
Cl2=CCl-CCl=ĊCl + Cl2C=CCl-C≡CCl
CCl=Cl2
+Cl
Acetylene Pathway I
+ Cl2C=CCl2
CCl=Cl2
+Cl
Acetylene Pathway II
+ Cl2C=ĊCl
CCl=Cl2
+Cl
Olefin Pathway

Figure 2.14. Chemically activated chlorine displacement and isomerization reaction channels to formation of hexachlorobenzene and octachlorostyrene. Chemically activated intermediates are not shown.

Octachloronaphthalene


+ ClC ≡ CCl
+ Cl
Acetylene Pathway I
+ ClC ≡ CCl
Acetylene Pathway II
+ Cl2C=ĊCl
+ 3 Cl
Olefin Pathway

Octachloroacenaphthylene

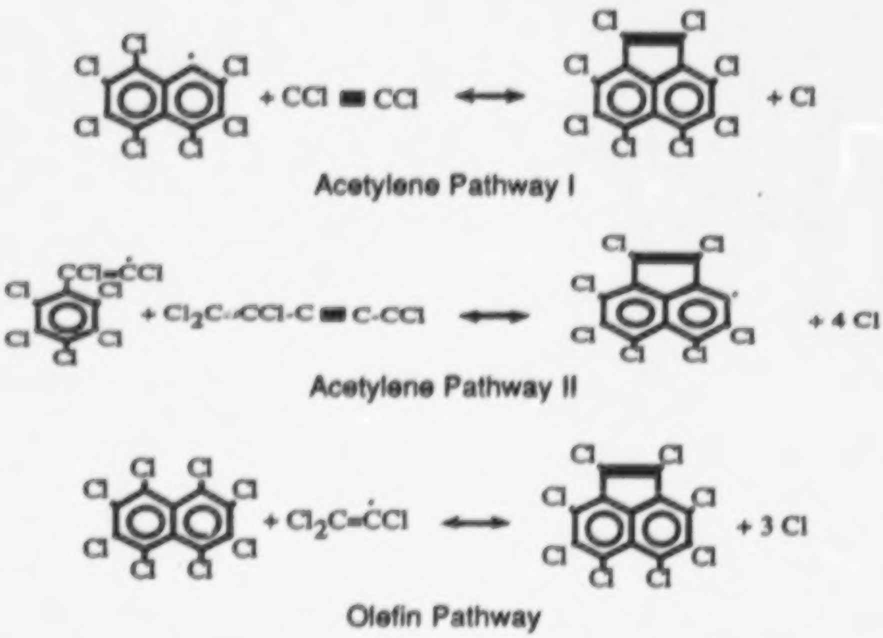

+ CCl ≡ CCl
+ Cl
Acetylene Pathway I
+ Cl2C=CCl-C ≡ C-CCl
+ 4 Cl
Acetylene Pathway II
+ Cl2C=ĊCl
+ 3 Cl
Olefin Pathway

Figure 2.15. Chemically activated chlorine displacement and isomerization reaction channels to formation of octachloronaphthalene and octachloroacenaphthylene. Chemically activated intermediates are not shown. Intermediate formation of the substituted olefin and its subsequent carbon-chlorine bond fission to form the radical are not shown for the octachloroacenaphthylene olefin reaction channels.

abstraction from Cl_2 by C_2Cl_3 and the slightly higher pyrolysis temperature of CCl_4 which may partially remove C_2Cl_2 from participation in molecular growth pathways.

Molecular growth reactions of the type observed from C_2Cl_4 pyrolysis are also implicated in the gas-phase formation of polychlorinated biphenyls (PCBs), polychlorinated dibenzo-p-dioxins (PCDDs), and polychlorinated dibenzofurans (PCDFs). Chlorinated benzenes and chlorinated phenols are suspected as precursors. Fundamental kinetic studies of condensation mechanisms leading to the formation of PCBs, PCDDs, and PCDFs are sparse. The following paragraphs summarize a recent study of the thermal reactions of chlorinated benzenes.[59,60]

Thermal reactions of chlorobenzene in H_2 and H_2/O_2 mixtures have been studied in tubular flow reactors of various composition and geometries. Experiments were conducted at atmospheric pressure over a temperature range of 562 - 1002°C. Gas-phase residence times ranged from 0.03-2.0 s. Complete conversion of chlorobenzene in H_2 required temperatures above 827°C, while in mixtures containing small quantities of O_2 equivalent conversion occurred at 662°C. Major products in both systems were benzene, soot, and HCl, with CH_4 and C_2H_6 also present in lower concentrations. Trace products included toluene, biphenyl isomers, C_2H_4, and C_2H_2. Carbon monoxide and carbon dioxide were also observed when oxygen was present.

Detailed kinetic mechanisms of elementary reactions were developed to model the experimental results using QRRK theory. In pure H_2, results indicated the initial step was C-Cl bond fission with Cl then rapidly producing HCl and H by the following reaction: $Cl + H_2 \longrightarrow HCl + H$. Displacement of Cl by H (H addition to the ring with subsequent β scission of the Cl from the activated chlorocyclohexadienyl radical) was identified as the key reaction for conversion of chlorobenzene. The authors also suggested that when present, O_2 can initiate a chain mechanism ($H_2 + O_2 \longrightarrow HO_2 + H$), thus explaining the lower temperature required for chlorobenzene conversion under oxidative versus pyrolytic conditions.

The molecule and radical thermodynamic properties required for the above models has led to the development of a data base for group additivity calculations of chlorinated aromatics including PCDDs and PCDFs. This data base includes estimates of bond energies, entropies, and heat capacities of radical intermediates in pathways to PCDD/PCDF formation. These properties demonstrate that it is thermodynamically more favorable to form PCDDs and PCDFs (especially the 2,3,7,8 isomer) over the respective non-chlorinated species. Analysis of potential mechanisms indicate two plausible regimes where homogeneous gas-phase PCDD/PCDF formation may occur in incineration systems. The first is a fuel-rich region where molecular growth may occur. The second is a region where polyphenols and aromatics may be present with oxygen and oxygenated radicals at temperatures which favor addition reactions over oxidation of the ring systems. Reactions in these regimes are very complex and previous studies indicate that the precursors to PCDD/PCDF formation are present at very low steady-state concentrations. Rapid condensation reactions appear capable of both forming and destroying dioxin precursors.

Mechanism 3: Radical-Radical and Radical-Molecule Association Reactions

Neither radical-radical (radical-atom) association nor radical-molecule addition reactions are expected to occur with large rates unless temperatures fall below 600°C. Association of radicals to form stable molecules are expected to occur only when molecule concentrations are low and/or radical concentrations are high (cf. Rxn 12):

$$CCl_3 + CH_3 \dashrightarrow CCl_3\text{-}CH_3 \qquad \text{(Rxn 12)}$$

These reaction rates are second-order with respect to radical concentration and are temperature independent or exhibit small negative temperature dependencies.[29] Since radical concentrations in the combustion zone are at least a factor of 100 less than stable molecule concentrations, it can be shown that the overall forward reaction rate for radical-molecule reactions are typically greater than 50 times radical-radical reaction rates at temperatures >1200°C and a factor of 10 at 800°C. Below 600°C, association reaction rates become the dominant pathways of PIC formation.

At temperatures <600°C, simple radical-molecule addition reactions may also become energetically favorable. These were excluded from the previous discussion of elementary reaction pathways in the combustion zones due to their reversibility at elevated temperatures. In the post-flame zones of full-scale incinerators, unreacted oxygen (O_2) is the molecular species in highest concentration. Radical - O_2 addition reactions (cf. Rxn 13).

$$C_2Cl_3 + O_2 \dashrightarrow COCl_2 + COCl \qquad \text{(Rxn 13)}$$

forming a variety of partial oxidation products are therefore expected to be important pathways of PIC formation in post-flame and quenching zones of full-scale systems.

A listing of second-order association rate constants for some polyatomic radicals are presented in Table 2.12. Rate constants are typically $10^{9.5 \pm 0.5}$ 1/mol-s and are independent of total pressure. In contrast, association of atoms or atoms and diatomics are pressure dependent and have pseudo-second-order rate constants of $10^{7.5 \pm 0.5}$ 1/mol-s at atmospheric pressure and combustion temperatures. As a consequence, the formation of diatomic and triatomic molecules is competitive by this mechanism only when the concentration of atoms or diatomic radicals exceeds that of polyatomic radicals by a factor of 100. Since this event is unlikely under all circumstances, recombination of polyatomic radicals with other polyatomic radicals, atoms and O_2 will contribute to PIC formation in the cool zones of full-scale systems.

The routes of formation of radicals were discussed in the previous sections on elementary reactions of POHCs. Their ultimate fate may be addressed from both a thermodynamic and kinetic viewpoint. Table 2.13 lists the Gibbs-free energies of formation at 1000 K ($\Delta G^\circ_{f,1000}$) of some common radicals and atoms. This information may be included in calculations with any number of standard combustion equilibrium codes (e.g., reference 53) to predict the concentration of individual radicals entering the cool zones of full-scale systems. However, one must be extremely cautious in using this approach. For example, only radical species for which mechanistically and kinetically reasonable pathways can be envisioned should be included in the

TABLE 2.12

ARRHENIUS PARAMETERS FOR SOME ASSOCIATION REACTIONS INVOLVING RADICALS

Reference[1]	Reaction	log A (l./mole-s)	E (kcal/mole)
a	$2CH_3 \rightarrow C_2H_6$	10.5±0.2	0
b	$2C_2H_5 \rightarrow C_4H_{10}$	10.0±0.5	0
c	$CH_3+C_2H_5 \rightarrow C_3H_8$	10.7	0
d	$2i\text{-}C_3H_7 \rightarrow (i\text{-}Pr)_2$	8.6	0
e	$2CF_3 \rightarrow C_2F_6$	9.5±0.3	0
f	$2CCl_3 \rightarrow C_2Cl_6$	9.6	0
g	2 Allyl→biallyl	9.9	0
h	$CH_3+O_2 \rightarrow CH_3O_2$	9.5	0(3rd order)
i	$C_2H_5+O_2 \rightarrow C_2H_5O_2$	9.6	0
j	$CH_3+NO \rightarrow CH_3NO$	8.8	0
k	$2CF_2 \rightarrow C_2F_4$	8.4	1.6
l	$CH_3+Cl \rightarrow CH_3Cl$	4×10^{11}	0
l	$CCl_3+Cl \rightarrow CCl_4$	2.5×10^{11}	0
l	$CH_2Cl+CH_2Cl \rightarrow C_2H_4Cl_2$	4×10^{9}	0
l	$CCl_3+CCl_3 \rightarrow C_2Cl_6$	6×10^{8}	0

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TABLE 2.13

THERMODYNAMIC PROPERTIES OF SELECTED RADICALS PRODUCED IN HAZARDOUS WASTE INCINERATION

Species	ΔH_f (300 K) (kcal/mole)	ΔG_f (1000 K) (kcal/mole)	Reference
H	52.103	39.562	a
OH	9.432	5.706	a
HO_2	4.996	16.021	a
O	59.562	44.875	a
F	18.863	4.522	a
FO	26.000	22.884	a
CFO	-41.000	-50.043	a
CF_2	-43.501	-50.947	a
CF_3	-112.403	-101.283	a
Cl	28.924	15.547	a
ClO	24.192	21.123	a
CClO	-15.000	-26.205	a
CCl_2	57.000	48.001	a
CCl_3	19.002	28.838	a
$CHCl_2$	24.058	27.807	b
CH_2Cl	28.260	30.807	b
CH_3	34.814	38.179	a
C_2F_5	-213.000	-171.048	b
C_2Cl_5	8.897	48.535	b
C_2HCl_4	5.387	40.618	b
$C_2H_2Cl_3$	11.800	45.032	b
C_2H_5	26.500	53.593	b
C_2Cl_3	53.000	55.363	b
C_2HCl_2	52.000	54.153	b
C_2H_3	69.000	64.452	b

TABLE 2.13

THERMODYNAMIC PROPERTIES OF SELECTED RADICALS PRODUCED IN HAZARDOUS WASTE INCINERATION (continued)

Species	ΔH_f(300 K) (kcal/mole)	ΔG_f(1000 K) (kcal/mole)	Reference
C_3H_5	40.600	64.112	b
$n-C_3H_7$	21.000	71.157	b
$i-C_3H_7$	17.600	69.693	b
C_6H_5	70.043	87.593	c
C_7H_7	45.000	93.430	b
C_6H_5O	11.400	NA	d

1. Bibliographic sources.

[a] Stull, D.R. and Prophet, H., JANAF Thermochemical Tables, 2nd Edition, NSRDS-NBS 37, National Bureau of Standards, Washington, D.C., 1971.

[b] Benson, S.W., Thermochemical Kinetics, 2nd ed., John Wiley, New York, 1976.

[c] Bahn, G.S., Approximate Thermochemical Tables for Some C-H-O Species, NASA CR-2178, 1973.

[d] MacMillen, A.F. and Golden, D.M. (1982), Ann. Res. Phys. Chem., 33, 493.

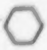
calculation. Common species such as H, OH, O, Cl, CH_3 will usually be included in every calculation. However, it is unlikely that a highly chlorinated radical such as C_2Cl_5 would be formed from a waste stream containing POHCs no more chlorinated than CH_2Cl_2 or C_6H_5Cl. The equilibrium calculation should also be performed at the temperature of the combustion zone, just upstream of the cool zone, with the assumption that the equilibrium is then "frozen in".

In the cool zone, the formation of molecular products may be readily calculated by simple kinetic codes.[61] The inputs are the concentrations from the equilibrium calculation and known or estimated rate constants for radical-radical and/or radical-molecule association reactions (cf. Table 2.12). It should be noted that one must modify this thermodynamically generated prediction of PICs in cool zones to allow for the formation of stable radicals that exist at "super-equilibrium" concentrations. The identification of these species is key to the successful prediction of PICs formed by association reactions. Thus, one must be able to effectively predict radical stability.

Bond strengths of radicals usually parallel their stability although exceptions do exist, e.g., highly stable radicals can be reactive and thus removed from a system. The activation energy for the decomposition of a radical into products is given by $Ea = \Delta H_R + E_r$, where ΔH_R is the enthalpy of the decomposition reaction and E_r is the activation energy of the reverse process. $E_r \sim 0$ for the decomposition of a radical into a diradical and radical or atom, e.g., $CCl_3 \dashrightarrow CCl_2 + Cl$. Some of the ΔH°_f's for radicals are known (cf. Table 2.13); however, ΔH°_f for most diradicals are not available. Thus, one must usually estimate the strength of the bond being broken (cf. Table 2.14). The bond strength of radicals undergoing this simple homolytic process sometimes parallels the bond energy of the first bond of similar type broken in the parent molecule. For example, the reaction $CH_4 \dashrightarrow CH_3 + H$ at 300 K involves breaking a 104 kcal/mole bond while C-H fission of the CH_3 radical at the same temperature also involves breaking a 104 kcal/mole bond. However, C-Cl fission of CCl_4 at 300 K involves breaking a 70 kcal/mole bond while C-Cl fission of CCl_3 breaks a 57

TABLE 2.14

SOME O-H, C-H, AND C-C SINGLE BOND STRENGTHS (DH°) IN RADICALS

Species RO-H	DH° (RO-H) kcal/mole	Species Containing C-H	DH° (C-H) kcal/mole	Species Containing C-C	DH° (C-C) kcal/mol
O-H	102	CH_2-H	106	CH_2-CH_2	96
OO-H	47	CH-H	106	CH_2CH_2-CH_3	25.5
CH_2O-H	31	C-H	81	$(CH_2)_2C$-CH_3	51
COO-H	12	CH_2CH_2-H	39	CHCH-CH_3	32
		OCH_2-H	22	-CH_3	27.5
		CO-H	19	-CH_3	35
		CHCH-H	43	 -CH_3	11.5
		CC-H	-125	$(CH_3)_2C(CH_2)$-CH_2	20
		$COCH_2$-H	43.5	OCH_2-CH_3	12
		CH_2CO-H	36	$(CH_3)_2C(O)$-CH_3	7
		allyl	60	CH_2CO-CH_3	30
		-H	40	OC-CH_3	11
		-H	47.5	O_2C-CH_3	-20
		-H	24		

kcal/mole bond. Examination of a large number of similar reactions indicates that C-Cl bonds in radicals are generally weaker than C-H bonds, as observed in their molecular analogues. Methyl and phenyl radicals are particularly stable due to the strength of the second C-H bond which must be broken for decomposition to occur.

This trend is modified when one of the decomposition products is a stable molecule. This will be the case for most straight- and branched-chain hydrocarbons and chlorocarbons (see Rxns 14a and 14b):

$C_2H_5 \dashrightarrow C_2H_4 + H \qquad \Delta H_{R,300} = 38.7$ kcal/mole (Rxn 14a)

$C_2Cl_5 \dashrightarrow C_2Cl_4 + Cl \qquad \Delta H_{R,300} = 17.6$ kcal/mole (Rxn 14b)

In this case, the energy required to break the second bond is much lower (cf. Table 2.14). Radicals in this class will generally undergo β -bond scission to form a molecule and the most stable radical, e.g., n-C_3Cl_7 ---> C_2Cl_4 + CCl_3 is preferred over n-C_3Cl_7 ---> C_3Cl_6 + Cl. The calculation of Ea requires knowledge of E_r and ΔH_R; Er is usually small, and on the order of 0-5 kcal/mole. Table 2.15 presents some typical rate data. Arrhenius pre-exponential factors are usually on the order of 10^{13} s^{-1}.

The end result of these various pathways for reaction is that there will be a tendency to form fragile, higher molecular weight PICs in the cool zones of full-scale systems. $CHCl_3$, CCl_4, and C_2Cl_6 are examples of fragile chlorocarbons that may form via various associations of CCl_3, Cl, and H atoms. Although relatively fragile, these compounds require minutes to hours to decompose at temperatures below 500°C. Thus, once formed they may persist and exit the stack of full-scale systems. Phenyl and chlorinated phenyl radicals may also recombine to form various PCBs. Nitrile radicals are also very stable and could readily form hydrogen cyanide (HCN) via association with H atoms, although yields may be reduced due to the pressure dependence of the reaction. Furthermore, association with CH_3 might be favored versus H to form acetonitrile (CH_3CN).

TABLE 2.15

RATE EXPRESSIONS FOR THE DECOMPOSITION OF SOME COMMON RADICALS[1]

Reaction	A(s^{-1})	Ea(kcal/mole)	Tqq(2)	Ref
$C_2H_5 \rightarrow C_2H_4 + H$	2×10^{13}	39.1	387	a
$nC_3H_7 \rightarrow C_2H_4 + CH_3$	1.3×10^{13}	30.4	248	a
$C_2H_4Cl \rightarrow C_2H_4 + Cl$	4×10^{13}	22.4	96	b
$CH_2ClCHCl \rightarrow C_2H_3Cl + Cl$	3×10^{13}	24.7	138	b
$CHCl_2CHCl \rightarrow CHClCHCl + Cl$	1.2×10^{13}	20.5	79	b
$C_2Cl_5 \rightarrow C_2Cl_4 + Cl$	3×10^{13}	17.9	25	b

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1. Bibliographic sources.

[a] Tsang, W.,(1985), J. Am. Chem. Soc. 107, 2873.

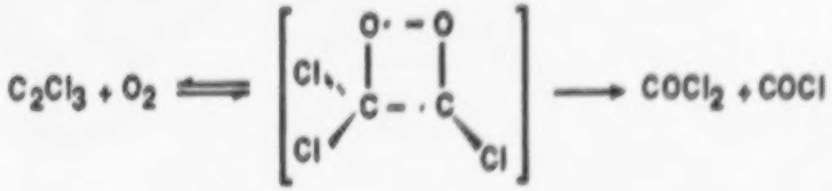
[b] Benson, S.W. and O'Neal, H.E.(1970) NSRDS-NBS 21, U.S. Government Printing Office, Washington, D.C.

Of the additional types of association reactions that may occur in the cool zones, radical- O_2 reactions are expected to be the most important. In the cool zones of incinerators, fuel/air mixing may now be sufficient that a significant quantity of oxygenated products may be produced that are stable at these temperatures. At temperatures $\leq$ 300°C, the primary reaction of O_2 is a reversible addition of the organic radical (R) (cf. Rxn 15):

$$R^{\cdot} + O_2 \text{ ---> } RO_2 \qquad \text{(Rxn 15)}$$

The peroxy radical ($ROO^{\cdot}$) can then abstract H to form the peroxide (ROOH) and initiate a chain process. Both the peroxide (and peroxy radical) can also undergo 0-0 bond fission to form OH (and 0) and the alkoxy radical ($RO^{\cdot}$). $RO^{\cdot}$ can then combine with or abstract a H atom to form the alcohol or undergo β bond homolysis to form the most stable aldehyde or ketone and a radical. Above 300°C, O_2 reacts primarily by H abstraction to form HO_2 and another radical in a chain-branching step.

Table 2.16 summarizes the limited data available concerning association reactions of O_2 and hydrocarbon radicals (and chlorocarbon radicals) that result in stable PIC formation.[62,63] It has been proposed[63] that the reaction proceeds through a four-membered dioxitanyl ring intermediate (cf. Rxn 16):



(Rxn 16)

Inspection of Table 2.16 indicates that vinyl radical (C_2H_3) forms formaldehyde (CH_2O) and formyl radical ($CHO^{\cdot}$) while C_2Cl_3 forms phosgene ($COCl_2$) and phosgenyl radical (COCl). Other substituted formaldehydes and formyl radicals are formed from other olefinic radicals depending on the nature and position of substitution. The rate constants for these reactions are similar at room temperature but decrease more rapidly with temperature for the more highly chlorinated species. This suggests that chlorinated olefins

TABLE 2.16

REACTION RATE PARAMETERS FOR COOL ZONE REACTIONS OF RADICALS AND O_2

Reaction	T (°K)	A (ℓ mole^{-1}s^{-1})	Ea (cal/mole)	Ref[1]
$CH_3 + O_2$ ---> $CH_3O_2^{\cdot}$	300	3.2×10^9	0	a
$C_2H_5 + O_2$ ---> $C_2H_5O_2^{\cdot}$	400	4.0×10^9	0	b
$C_2H_3 + O_2$ ---> CH_2O+CHO	297-602	4.0×10^9	-290	c
$CH_3CH{=}CH+O_2$ ---> CH_3CHO+HCO	296-600	4.3×10^9	0	d
CH_2CCl+O_2 ---> $COCl_2$+COCl	298-648	3.0×10^9	-330	e
$C_2Cl_3+O_2$ ---> CCl_2O+COCl	298-648	1.2×10^9	-830	e

[1] Bibliographic sources.

[a] Sleppy, W. C. and Calvert, J. G., (1959), *J. Amer. Chem. Soc.*, 81, 769.

[b] Dingledy, D. P. and Calvert, J. G., (1963), ibid, 85, 856.

[c] Slagle, I. R., Park, J-Y, Heaven, M. C., and Gutman, D., (1984) *J. Amer. Chem*.

[d] Slagle, I. R., Bernhardt, J. R., and Gutman, D. (1989), *22nd Symp. (Int.) on Combustion*, in press.

[e] Russell, J. J., Seetula, J. A., Gutman, D., and Senkan, S. M. (1989), *J. Phys. Chem*., 93, 1934.

will be less reactive with O_2 than their hydrocarbon counterparts at temperatures between 100°C - 300°C, and thus more likely to undergo association or β-bond scission. β-bond scission may be especially favorable due to the weaker C-Cl bond.

Literature Summary of PIC Formation Studies

The majority of the information available in the literature concerning PIC formation for toxic organic compounds has been generated by researchers at the University of Dayton. A summary of PIC data reported in a variety of government reports and publications is summarized in Table 2.17.[16] Table 2.18 presents the results of one particularly detailed study.[64]

In this study, the thermal degradation of a five component mixture of toxic organic compounds (chlorobenzene, trichloroethylene, carbon tetrachloride, 1,1,2-trichloro-1,2,2-trifluoroethane, and toluene, referred to as Hazardous Waste Mixture #1, (HWM-1)) was studied. The mixture was studied in three reaction atmospheres: oxygen-starved, stoichiometric oxygen, and oxygen-rich. The behavior of the components in the mixture was compared to their behavior when tested as pure compounds and the thermal reaction products were identified. Thermal decomposition behavior was analyzed and related to elementary chemical reaction kinetics. Benzaldehyde, phenol, and benzofuran were the only observed O_2-containing products under oxidative or pyrolytic conditions while numerous complex pyrolysis-type products were observed. This indicates that most products resulted from radical-molecule reactions and association of radical fragments. OH and O addition products were not significant. The lack of addition products suggests that OH and O were more likely to participate in abstraction reactions at high temperatures or that the intermediate addition products were not very stable.

Experimental results of other miscellaneous studies reported in the literature are presented in Table 2.19.

TABLE 2.17

Summary of Reaction Products Observed from Thermal Decomposition of Various Materials in UDRI Flow Reactor

Parent	Product	Conditions
Kepone	Hexachlorobenzene Hexachlorocyclopentadiene Hexachloroindenone	Air atmosphere
p,p'-DDT	o,'p-DDT p,p'-DDE o,p'-DDE	Air atmosphere
Mirex	Hexachlorocyclopentadione Hexachlorobenzene	Air atmosphere
polyacrylonitrile, poly-methacrylonitrile	Acrylonitrile Methacrylonitrile Acetonitrile Hydrogen cyanide Styrene Methyl acrylate	Air and helium atmospheres
Freon 113	Trichlorofluoroethene Tetrachlorodifluoroethane	Air atmosphere, $\bar{t}_r^{a} = 2.0$ s
Carbon Tetrachloride	Tetrachloroethene Hexachloroethane Hexachlorobutadiene	Air atmosphere, $\bar{t}_r = 2.0$ s
Toluene	1,5-Hexadiyne 1,5-Hexadien-3-yne Benzene Ethylbenzene Ethenylbenzene Benzaldehyde Benzofuran $C_{10}H_8$	Air atmosphere, $\bar{t}_r = 2.0$ s
Chlorobenzene	Benzene Ethylnylbenzene Benzaldehyde 1H-Indene $C_{10}H_8$	Air atmosphere, $\bar{t}_r = 2.0$ s
Pentachloronitrobenzene	Hexachlorobenzene	Air atmosphere, $\bar{t}_r = 2.0$ s
Chloroform	CCl_4 $1,2\text{-}C_2H_2Cl_2$ C_2HCl_3 C_2Cl_4 C_2HCl_5 C_2Cl_2	$\phi^{b} = 0.67$, $\bar{t}_r = 2.0$ s

TABLE 2.17

Summary of Reaction Products Observed from Thermal Decomposition of Various Materials in UDRI Flow Reactor (continued)

Chloroform	$C_2H_2Cl_4$ C_3Cl_4 C_4Cl_6 C_6Cl_6	
Chloroform	Carbon tetrachloride Trichloroethene Pentachloroethane Dichloroethyne Tetrachloroethene Tetrachloropropyne 1,1,2,4-Tetrachloro-1-buten -3-yne Hexachlorobutadiene	ϕ=0.76 and nitrogen atmospheres
Pentachloroethane	Chloroform Carbon tetrachloride Dichloroethane Tetrachloroethane Trichloroethene Dichloroethyne Tetrachloroethene Hexachloroethane Dichloropropane Tetrachloropropyne Hexachlorobutene	ϕ=0.76 and nitrogen atmospheres
1,2,4-Trichlorobenzene	Chlorobenzene o,m-,and p-Dichlorobenzene Trichlorobenzene isomers	Air, nitrogen, and ϕ=1.0 atmospheres
2,2',5,5',-Tetrachlorobiphenyl	Trichlorobenzene Biphenyl Tetrachlorobenzene Monochlorobiphenyl Chlorinated compound MW 204 Dichlorobiphenyl Chlorinated compound MW 230 + (2 isomers) Trichlorobiphenyl (2 isomers) Dichlorodibenzofuran Tetrachlorobiphenyl (2 isomers) Pentachlorobiphenyl (2 isomers) Trichlorodibenzofuran	Air atmosphere, $\bar{t}_r$=2.0 s
2,2',4,5,5'-Pentachlorobiphenyl	Trichlorobenzene Tetrachlorobenzene (2 isomers) Monochlorobiphenyl Trichlorobiphenyl Pentachlorobenzene Trichlorobiphenyl	Air atmosphere, $\bar{t}_r$=2.0 s

TABLE 2.17

Summary of Reaction Products Observed from Thermal Decomposition of Various Materials in UDRI Flow Reactor (continued)

	Tetrachlorobiphenyl Pentachlorobiphenyl Trichlorodibenzofuran Hexachlorobenzene Chlorinated compound MW 264+ (3 isomers) Tetrachlorodibenzofuran (2 isomers) Hexachlorobiphenyl	
2,2',4,4',5,5'-Hexachlorobiphenyl	Tetrachlorobenzene Pentachlorobenzene Trichlorobiphenyl Hexachlorobenzene Hexachlorobiphenyl Heptachlorobiphenyl Pentachlorodibenzofuran Chlorinated compound MW 288+	Air atmosphere, $\bar{t}_r$=2.0 s
2,3',4,4',5-Pentachlorobiphenyl	Tetrachlorodibenzofurans Trichlorodibenzofurans Pentachlorodibenzofuran Tetrachlorobiphenyls Trichlorobiphenyl Trichlorobenzene Dichlorobenzene Trichloronaphthalene Tetrachloronaphthalene Trichlorophenylethynes Dichlorophenylethyne Tetrachlorobiphenylenes C_9H_8OCl $C_{10}H_3Cl_3$	
Pentachlorophenol	Dichlorobutadiyne Tetrachloroethene Tetrachloropropyne Trichlorofuran 1,1,2,4-Tetrachloro-1-buten-3-yne Tetrachlorofuran Trichlorobenzene Tetrachlorobenzene Pentachlorobenzene Hexachlorobenzene Octachlorostyrene Hexachlorodihydronaphthalene Octachloronaphthalene Octachlorodibenzo-p-dioxin	Air and nitrogen atmospheres, $\bar{t}_r$=2.0 s

TABLE 2.17

Summary of Reaction Products Observed from Thermal Decomposition of Various Materials in UDRI Flow Reactor (continued)

Mixture of 2,6-Dichlorobiphenyl/ 2,2'-Dibromobiphenyl	Dibenzofuran Fluorenone Xanthenone	Air atmosphere $\bar{t}_r$=2.0 s
Hex Wastes (Industrial mixtures)	Hexachlorobenzene Hexachloroindenone	Air atmosphere $\bar{t}_r$=2.0 s
Mixture of Methanol Dichloromethane Acetone 1,1,1-Trichloroethane Acetonitrile Chloroform MEK 1,2-Dichloroethane Toluene Dioxane Pyridine	Methyl vinyl ketone Benzaldehyde Cyanobutadiene Acrylonitrile Ethylbenzene Chloroacetone Styrene Acetic acid Benzofuran Benzodioxide Benzylchloride Phenol Dichloroethylene Chlorophenol Cresol	Air atmosphere $\bar{t}_r$=2.0 s
Mixture of CCl_4 - 53% $CHCl_3$ - 33% CH_2Cl_2 - 7% CH_3Cl - 7%	CCl_4 $CHCl_3$ CH_2Cl_2 CH_3Cl 1,1-$C_2H_2Cl_2$ C_2HCl_3 C_2Cl_4 C_2Cl_6	ϕ=0.05, $\bar{t}_r$=2.0 s
Mixture of CCl_4 - 53% $CHCl_3$ - 33% CH_2Cl_2 - 7% CH_3Cl - 7%	CCl_4 $CHCl_3$ CH_2Cl_2 CH_3Cl C_2Cl_2 1,1-$C_2H_2Cl_2$ C_2HCl_3 C_2Cl_4 C_2Cl_6 C_3Cl_4 C_4Cl_4 C_4Cl_6 C_6Cl_6 C_8Cl_8	Pyrolytic, $\bar{t}_r$=2.0 s

TABLE 2.17

Summary of Reaction Products Observed from Thermal Decomposition of Various Materials in UDRI Flow Reactor (continued)

Mixture of CCl_4 - 10% $CHCl_3$ - 20% CH_2Cl_2 - 30% CH_3Cl - 40%	CCl_4 $CHCl_3$ CH_2Cl_2 CH_3Cl 1,1-$C_2H_2Cl_2$ 1,2-$C_2H_2Cl_2$ $C_2H_4Cl_2$ C_2HCl_3 C_2Cl_4	ϕ=0.05, $\bar{t}_r$=2.0 s
Mixture of CCl_4 - 10% $CHCl_3$ - 20% CH_2Cl_2 - 30% CH_3Cl - 40%	CCl_4 $CHCl_3$ CH_2Cl_2 CH_3Cl C_2Cl_2 1,1-$C_2H_2Cl_2$ 1,2-$C_2H_2Cl_2$ $C_2H_4Cl_2$ C_2HCl_3 C_2Cl_4 C_3Cl_4	Pyrolytic, $\bar{t}_r$=2.0 s
Mixture of Heptachlor Pentachlorophenol Diphenylnitrosamine Pyrene	9H-carbazole chlorocyclopentadiene tetrachlorofuran trichlorodihydronaphthalene dichloroacetylene tetrachloropropyne pentachloronaphthalene biphenyldicarbonitrile diphenylamine or aminobiphenyl hexachlorodihydronaphthalene tetrachlorobenzene pentachlorobenzene trichloronaphthalene tetrachloronaphthalene benzene acenaphthylene or biphenylene hexachloromethanocyclohexene benzonitrile naphthalene or azulene	Air and N_2 atmospheres $\bar{t}_r$=2.0 s
Mixture of butyl benzyl phthalate 2,3',4,4',5-pentachlorobiphenyl azobenzene	toluene benzaldehyde methylphenol or benzyl alcohol benzene styrene phenol Unknown	air and N_2 atmospheres $\bar{t}_r$=2.0 s

TABLE 2.17

Summary of Reaction Products Observed from Thermal Decomposition of Various Materials in UDRI Flow Reactor (continued)

Nonlyphenol (technical grade)	C_9-Alkene or C_9-cycloalkane	air and N_2 atmospheres $\bar{t}_r$=2.0 s
	methylbenzofuran	
	phenol	
	benzofuran	
	C_3-alkenylphenol or hydroxyldihydroindene or benzopyran or propenyloxybenzene	
	C_4-alkenylphenol or hydroxymethyldihydroindene or methylbenzopyran or butenyloxybenzene	
	naphthalenol	
	C_5-alkenylphenol or isomer	
	toluene	
	C_3-alkenylbenzene	
	benzene	
	C_3-benzene	
	1H-Indene	
	dihydrobenzofuran or hydroxystyrene	
	phenylacetylene	
	C_6-alkadienylbenzene	
	C_7-alkadienylbenzene	
	ethylbenzene	
	xylene	
	styrene	
	methyl-1H-indene	
	naphthalene or azulene	
	C_7-Diyne-ene or C_7-cyclodiyne or C_7-cyclodiene-yne	
	C_6-alkenylphenol or isomer	
	C_7-alkenylphenol or isomer	
	phthalic anhydride	
	cyclohexadiene or C_6-ene-yne	
	acenaphthylene or biphenylene	
	biphenyl or acenaphthene	
	unknown(s)	

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[a] $\bar{t}_r$ is the mean gas phase resident time.

[b] ϕ is the fuel/air equivalence ratio.

TABLE 2.18

THERMAL REACTION PRODUCTS OBSERVED FROM THE THERMAL DECOMPOSITION OF HWM-1

Formula	Identification	$\phi=0.06$	$\phi=1.0$	Pyrolysis
$CHCl_3$	Trichloromethane	x		
$C_2H_3ClF_2$	Chlorodifluoroethane		x	
$C_2H_2Cl_2$	1,1-Dichloroethene	x	x	x
C_2Cl_3F	Trichlorofluoroethene		x	x
C_2Cl_4	Tetrachloroethene		x	
$C_4H_4Cl_2$	Dichlorobutadiene		x	
C_6H_6	Benzene	x	x	x
C_6H_6	1,5-Hexadiyne 1,5-Hexadien-3-yne	x	x	x
C_6H_6O	Phenol	x	x	x
C_6H_5F	Fluorobenzene		x	x
$C_6H_5C_{10}$	Chlorophenol	x	x	
$C_6H_4Cl_2$	Dichlorohexadiyne Dichlorohexadiene-yne		x	
$C_6H_4Cl_2$	Dichlorobenzene	x	x	
C_7H_8O	Methylphenol	x	x	
C_7H_7Cl	Chloromethylbenzene	x	x	x
$C_7H_6O_2$	Hydroxy-benzaldehyde Benzodioxol	x		
C_7H_6O	Benzaldehyde	x	x	
C_8H_{10}	Ethylbenzene	x	x	x
C_8H_8	Ethenylbenzene (Styrene)	x	x	x
C_8H_7Cl	Chloroethenylbenzene	x	x	x
C_8H_6	Ethynylbenzene	x	x	x
$C_8H_6Cl_2$	Dichloro-ethenylbenzene Chloroethenyl-chlorobenzene	x	x	x

TABLE 2.18

Thermal Reaction Products Observed from the Thermal Decomposition of HWM-1 (continued)

C_8H_6ClF	Chloro-fluoroethenyl-benzene		x	x
$C_8H_6F_2$	Difluoro-ethenylbenzene		x	x
C_8H_6O	Benzofuran	x	x	
C_8H_5Cl	Chloro-ethynylbenzene			x
$C_8H_5Cl_3$	Trichloroethenylbenzene	x		
C_8H_5ClO	Chlorobenzofuran	x	x	x
$C_8H_5F_3$	?			x
C_9H_8	1H-indene		x	x
$C_9H_8Cl_2$	Dichloro-propenylbenzene	x		x
	Chloropropenylchlorobenzene			
C_9H_8O	Phenylpropenal	x		
$C_9H_7Cl_3$	?		x	x
C_9H_7ClO	Chloromethylbenzofuran		x	
C_9H_6O	Phenyl-propynone	x		
$C_{10}H_8$	Azulene		x	x
	Napthalene			
	Methylene-1H-indene			
$C_{10}H_8ClF$	?			x
$C_{10}H_7Cl$	Chloronaphthalene			x
$C_{10}H_6Cl_2$	Dichloronaphthaline	x	x	x
$C_{10}H_5Cl_3$	Trichloronaphthaline	x		
$C_{11}H_{10}$	1-Methyl-naphthalene		x	
$C_{11}H_{10}$	2-Methyl-naphthalene		x	
$C_{11}H_{10}$	Methylnaphthalene			x
$C_{12}H_{10}$	Biphenyl		x	x
$C_{12}H_8O$	Dibenzofuran	x	x	
$C_{13}H_{12}$	1,1-methylenebis-benzene			x
$C_{13}H_{10}$	9H-Fluorene		x	x
$C_{13}H_{10}O$	Diphenylmethanone	x		
$C_{13}H_8O_2$	9H-Xanthen-9-one	x	x	
$C_{14}H_{14}$	1,1'-(1,2-ethanediyl)bis-benzene	x	x	x
$C_{14}H_{12}$	Methylfluoroene			x

TABLE 2.18
Thermal Reaction Products Observed from the Thermal Decomposition of HWM-1 (continued)

$C_{16}H_{10}ClF$	?	x
$C_{16}H_9F$	Fluoropyrene	x
	Fluorofluoroanthene	
$C_{17}H_{12}$	11H-Benzo[a]fluorene	x
	11H-Benzo[b]fluorene	

Table 2.19

SUMMARY OF REACTION PRODUCTS OBSERVED FROM LITERATURE THERMAL DECOMPOSITION STUDIES

Parent	Products	Conditions	Ref[a]
Chloromethane	ethene, ethane, acetylene, chloroethene, chloroethane	shock tube study, pyrolysis in methane 1200-2600 K 2.5E-5 mol/cm^3 500 μs	a
Chloromethane	ethene, ethane, acetylene, carbon monoxide, chloroethene, chloroethane	shock tube study preignition study in methane stoic. O_2/10% N_2/Ar mix 1200-2600 K 2.5E-5 mol/cm^3 500 μs	a
Methane	carbon dioxide, carbon monoxide, acetylene, ethene, ethane	methane/air flame study ϕ = 1.15-1.35	a
Chloromethane	carbon dioxide, carbon monoxide acetylene, ethene, ethane, methane chloroethene, dichloromethane, ethanol, methanol, trichloroethene, chloroethane, carbon tetrachloride	methane/air flame study ϕ = 1.15-1.35	a
Chloromethane	carbon, hydrogen, acetylene, ethene benzene	flow reactor study pyrolysis in methane 1260-1310K 0.03-3 sec	b
Chloromethane	acetylene, ethene, chloroethene methane, hydrogen chloride hydrogen, carbon monoxide carbon dioxide, benzene, water formaldehyde	flow reactor study oxidation in Ar carrier 1253 K	b
Chlorobenzene	acetylene, ethene, chloroethene methane, hydrogen chloride hydrogen, benzene, dichloromethane	flow reactor and shock tube pyrolysis in Ar carrier 1253 K, 1346-2472K 500-1000 μs	c,q
Chloromethane/Methane	methane, carbon dioxide, carbon monoxide, acetylene, ethene, hydrogen, hydrogen chloride water, dichloromethane, chloroethane chloroethene, benzene	$CH_4/CH_3Cl/O_2/Ar$ flame ϕ =1.79	d
Dichloromethane	acetylene, chloromethane, chloroethylene, 1,2-dichloroethene trichloroethene, carbon dioxide, carbon monoxide	shock tube study oxidative 1250-1650K 2.25E-5mol/cm3 500 μs	e

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Table 2.19 cont'd

SUMMARY OF REACTION PRODUCTS OBSERVED FROM LITERATURE THERMAL DECOMPOSITION STUDIES

Parent	Products	Conditions	Ref.
Dichloromethane	acetylene, chloromethane, chloromethane, 1,1-dichloroethene, 1,2-dichloroethene, trichloroethene, carbon	shock tube studies pyrolysis 1250-1650K 2.25E-5mol/cm3 500 μs	e,q
Dichloromethane	carbon monoxide, carbon dioxide chloromethane, tetrachloroethylene 1,1-dichloroethene, 1,2-dichloroethene, chloroform, chloroethene acetylene, ethene, trichloroethene	CH_4/air flame studies CHC:CH4 = 0.99, ϕ =.8 CHC:CH4 = 5.07, ϕ =.8	f
Dichloromethane	carbon monoxide, carbon dioxide chloromethane, tetrachloroethene 1,1-dichloroethene, 1,2-dichloroethene, chloroform, chloroethene acetylene, ethene, trichloroethene, hydrogen chloride, water	CH_4/Air flame studies Cl:H = 0.06, ϕ = 0.8 Cl:H = .33, ϕ = 0.8 Cl:H = 0.72, ϕ = 0.8	g
Dichloromethane	chloromethane, chloroform, chloroethylene, 1,1-dichloroethene 1,2-dichloroethene, trichloroethene tetrachloroethene	CH_4/Air flame studies 1800K Cl:H=0.06 - 0.72 ϕ = 0.8 - 1.1	h
Dichloromethane/ 1,1,1-Trichloroethane	1,1-dichloroethylene, 1,1-dichloroethane, chloroethylene, chloromethane, hydrogen chloride	flow reactor studies pyrolysis, H_2 atm. 848 and 1083 K 0.06 - 2 s	i
Chloroform	hexachloroethane, tetrachloroethene carbon tetrachloride	flow reactor studies air atm. 573 - 1323 K 5 s	j
Chloroform	hexachloroethane, hexachloropropene, tetrachloroethene, carbon tetrachloride, dichloroethene, trichloroethene dichloroacetylene,tetrachloropropyne dichlorobutadiyne, pentachloroethane tetrachloropropene, tetrachloro-1-buten-3-yne, pentachloro-1,3-butadiene hexachloro-1,3-butadiene,hexachloro-1-penten-3-yne	flow reactor studies H_2 atm 573 - 1323 K 0.5 s	j

Table 2.19 cont'd

SUMMARY OF REACTION PRODUCTS OBSERVED FROM LITERATURE THERMAL DECOMPOSITION STUDIES

Parent	Products	Conditions	Ref.
Chloroform/Methane	tetrachloroethene, trichloroethene dichloromethane, hydrogen chloride, 1,1-dichloroethene, chloroethene, chloroacetylene, methane, ethane, ethene,chloroethane,1,1,2,2-tetrachloroethane	shock tube studies pyrolysis 1000-1200K 2.4-3.9e-5 mol/cm^3 1 ms	k
Chloroform	tetrachloroethane, dichloromethane, trichloroethene,pentachloroethane, ethane, tetrachloroethene, hydrogen chloride, benzene, chloroethylene, carbon tetrachloride, 1,2-dichloroethene (cis and trans)	pyrolysis 723 - 798 K	l
Carbon tetrachloride	carbon dioxide, carbon monoxide, acetylene,ethene, ethane, chloromethane, dichloromethane, tetrachloroethylene chloroform, 1,2-dichloroethylene, dichloropropene, toluene, 1,1,1-trichloroethane	full-scale rotary kiln study CH_4/air atm. 1073 K, kiln 1273 K, secondary chamber 2 s	m
Bromomethane, Dibromomethane, Bromoform/Toluene	methane, acetylene, hydrogen bromide, dibromomethane, bromine	720 - 1170K	n
Trichloroethene/water	ethane, ethene, ethyne,propene, propyne,carbon, chloromethane, dichloromethane, chloroethene, dichloroethene, trichloroethene, chloroacetylene, tetrachloroethene	flow reactor studies H_2O vapor atm 800 K 0.036 - 0.01 s	o
Trichloroethene/hydrogen	acetylene, ethane, ethene,ethyne butane, butene, 1,3-butadiyne benzene, toluene, carbon, chloroform dichloroethene,trichloroethene chloroacetylene, tetrachlorethene chlorobenzene	flow reactor studies H_2 atm. 460 K 0.036-0.01s	o
Chloroform/hydrogen	ethane, ethene, ethyne, propane, propene,propyne, butene,butyne, 1-buten-3-yne, 1,3-butadiyne, benzene, carbon, methane, chloromethane,dichloromethane, chloroform, chloroethane, chloroethene	flow reactor studies H_2 atm 460 K 0.036 - 0.01s	o

Table 2.19 cont'd

SUMMARY OF REACTION PRODUCTS OBSERVED FROM LITERATURE THERMAL DECOMPOSITION STUDIES

Parent	Products	Conditions	Ref.
Chlorobenzene/hydrogen	acetylene, propane, propene, propyne, butene, butyne, 1-buten-3-yne, 1,3-butadiyne, 1,3-pentadiene, benzene, toluene, carbon, methane	flow reactor studies H_2 atm. 460K 0.035 - 0.01s	o
Chloroform	hexachloroethane, tetrachloroethene, carbon tetrachloride	flow reactor studies air 723 - 898 K 2 s	p
Pentachloronitrobenzene	hexachlorobenzene	flow reactor studies air 744 - 844 2 s	p
Ethylene/chlorine atom	acetylene, hydrogen chloride	very low pressure reactor study	r
Chloropentane, 1,1,2,2-tetrachloroethane, heptane	(not complete, only specific cmpds) dichloromethane, chloroform, benzene,carbon tetrachloride, trichloroethene, toluene, chlorobenzene	turbulent flame study air 792 K	s
1,1,2,2-Tetrachloroethane trichlorobenzene, heptane	(not complete, only specific cmpds) dichloromethane, chloroform, benzene, carbon tetrachloride, trichloroethene, toluene, chlorobenzene	turbulent flame study air 755 K	s
Tetrachloroethene trichlorobenzene, heptane	(not complete, only specific cmpds) dichloromethane, chloroform, benzene, carbon tetrachloride, trichloroethene, toluene, chlorobenzene	turbulent flame study air 777 K	s
Trichloroethylene, trichlorobenzene, heptane	(not complete, only specific cmpds) dichloromethane, chloroform, benzene, carbon tetrachloride, trichloroethene, toluene, chlorobenzene	turbulent flame study air 749 K	s
Trichloroethylene, trichlorobenzene, heptane	(not complete, only specific cmpds) dichloromethane, chloroform, benzene, carbon tetrachloride, trichloroethene, toluene, chlorobenzene	turbulent flame study air 780 K	s
Chloroethane	chloroethylene, hydrogen chloride	flow study, 823 K	t
1,1-Dichloroethane	chloroethylene, hydrogen chloride	flow study, 773 K	
1,2-Dichloroethane	chloroethene, dichloroethene hydrogen chloride	flow study, 773 K	

Table 2.19 cont'd

SUMMARY OF REACTION PRODUCTS OBSERVED FROM LITERATURE THERMAL DECOMPOSITION STUDIES

Parent	Products	Conditions	Ref.
1,1,2-Trichloroethane	1,2-dichloroethene (cis and trans-), 1,1-dichloroethene, hydrogen chloride	flow study, 773 K	t
1,1,2,2-Tetrachloroethane	trichloroethene, hydrogen chloride	flow study,723 K	t
Pentachloroethane	tetrachloroethene, hydrogen chloride	flow study,723 K	t
2,2-Dichloropropane	chloropropane, hydrogen chloride	flow study,723 K	t
1-Chloronaphthalene	naphthalene, hydrogen chloride	flow study,673 K	t
2-Chloronaphthalene	naphthalene, hydrogen chloride	flow study,773 K	t
Pentachloroethane/toluene	dichloromethane, chloroform, trichloroethene, tetrachloroethene styrene, hydrogen chloride	flow reactor studies pyrolysis, He atm 820 - 865 K 1 - 10 s	u
Chorobenzene/ 1,2-Dichlorobenzene	hydrogen chloride, carbon,benzene dichlorostyrene, chlorostyrene	flow reactor studies H_2 or He pyrolysis 1073 - 1273 K 0.02 - 2.7s	v,w
Chlorobenzene/hydrogen	hydrogen chloride, benzene, carbon, 1,3-pentadiene, toluene, naphthalene,, biphenyls, methane	flow reactor studies pyrolysis 1060-1275 KK	x
Chlorobenzene/helium	hydrogen chloride, benzene, carbon, 1,3-pentadiene, toluene, naphthalene,biphenyls, methane	flow reactor studies pyrolysis 1060 - 1275 K	x
Dibromomethane/argon	hydrogen bromide, carbon, carbon dioxide, bromine, acetylene	700 - 1200 K	y
Bromomethane/Argon	methane, hydrogen bromide, dibromomethane, acetylene, carbon	700 - 1200 K	y
Tribromomethane	hydrogen bromide, bromine radical, dibromoacetylene, hydrogen radical	pyrolytic/electon impact stydies 15 eV	z
Tetrabromomethane	bromine, tribromomethyl radical, dibromomethene radical, bromine atom, bromoacetyl radical	pyrolytic/electon impact stydies 15 eV	z
Pentachloroethane	tetrachloroethene, hydrogen chloride chlorine, trichloroethene	flow reactor studies pyrolysis	aa
Pentachloroethane	tetrachloroethene, hydrogen chloride trichloroethene, chlorine	flow reactor studies pyrolysis He carrier 680 - 711 K 8 - 35 s	ab
1,1,1-Trichloroethane	1,1-dichloroethylene, hydrogen chloride, chloroethene, chloroacetylene,, trichloroethene	flow reactor studies air 479 - 878 K 4 - 8 s	ac

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SECTION 3

PILOT- AND FULL-SCALE EMISSIONS ANALYSIS

This section presents an analysis of PIC emissions data from pilot- and full-scale facilities. Background information is presented about the variability in system designs, combustion conditions and overall quality of the emissions data. Then is presented an analysis of emissions data from hazardous waste incinerators[17,19,65-70], boilers co-firing hazardous wastes[71-75], and cement kilns using hazardous wastes as supplemental fuel.[76-85] Nine incinerator[17,19], 4 boiler, and 4 kiln test burns[76,81,82] were found to have sufficient data for analysis. A summary of the emissions sources are presented in Appendices A-C.

Then is presented an analysis of available pilot-scale emissions data from combustion designs simulating full-scale liquid injection and rotary kiln hazardous waste incinerators (and combinations thereof)[86,87,91-97,99-108] and boilers co-firing hazardous wastes.[88-90,98] Three US-EPA Incineration Research Facility (IRF) tests were found to have sufficient data for analysis.[96,97,99] A summary of the emission sources evaluated are presented in Appendix D. Important aspects of the remaining studies, i.e., those not containing quantitative emissions data, are discussed in the context of the findings of the emissions analysis.

The following questions are addressed by this analysis: 1) what are the average relative magnitudes of total organic PICs versus chlorinated PICs when normalized to input POHC and input chlorinated POHC concentrations, respectively? 2) To what degree are total organic emissions being fully characterized in full-scale systems? 3) What is the frequency of occurrence, arithmetic mean emission rates, and geometric mean emission rates of PICs identified as distinguishable chemical compounds? and 4) Based on the preceding analysis of the laboratory-scale PIC database, what are the predominant reaction mechanisms for PIC formation? The conclusion summarizes the important findings of these sections.

Background on Source Tests and Facilities

The largest degree of variation in system designs, combustion conditions, and quality of emissions data occurred within the nine incinerator emission sources. The wide distribution of incinerator types and control devices is shown in Table 3.1. Each facility had unique design or operating features. Multiple combustion chambers were prevalent, some with separate waste feed injection ports. Example arrangements of multiple chambers were parallel chambers, e.g., a rotary kiln for solids and a separate liquid injection unit for aqueous and organic wastes, or primary and secondary chambers in series.

As demonstrated in Table 3.2, these facilities also exhibited a wide range of key combustion parameters and heat input. Temperature and excess air readings are those recorded on each facility's instruments. They represent a fair picture of the range of values. However, intercomparison between facilities is unwise because these measurements are point values and do not reflect the distribution of values which are likely occurring within any one system. Residence times were calculated based on the combustion chamber volume and average flow rates, and the range of values must only be treated as representative of the variable nature of the different systems.

The composition of the various solid, liquid, or gaseous waste streams varied widely from site to site. Higher heating values were below 4,600 kJ/kg for aqueous liquids, ranged from 14,000 to 37,000 kJ/kg for organic liquids, and varied from 0 to 29,000 kJ/kg for solid wastes. The organic liquids (and many of the solid wastes) had heating values sufficient to sustain combustion without auxiliary fuel. Percent chlorine varied from ~ 0 to 25%, with the highest values occurring for organic liquids (chlorinated solvents). Ash content was negligible for most aqueous liquids, ranging from ~ 0 to 9% for organic liquids, and 17% to 29% for solid wastes. Water content was obviously high for aqueous wastes although values were not specified.

Operating conditions during the tests were those selected by the various plants as their normal conditions. In general, existing operating

TABLE 3.1

Distribution of Incinerator Types and Control Devices

Incinerator Type	# of Facilities
Liquid Injection	8
Rotary Kiln	3
Hearth	2
Gas Injection	1

Control Device	# of Facilities
None	3
HCl scrubber	6
Particulate control	5

TABLE 3.2

Range of Combustion Parameters - Incinerators

Temperature, °C[1]: 650 - 1450

Residence time, s[2]: 0.07 - 6.5

Oxygen concentration, %[3]: 8-12.0

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[1] Range of thermocouple readings in combustor(s)
[2] Estimated
[3] Stack measurement, dry basis

problems were corrected before emissions data was collected. With the exception a few runs conducted for the Dow Chemical and TWI, Inc. studies, effects of various failure modes and poor combustion conditions on emission rates were not investigated.

Organic emission samples were collected using three different sampling procedures. Gas bags and the volatile organic sampling train (VOST) were employed for volatile constituents (B.P. $\leq$ 120°C). The modified method 5 (MM5) sampling train was used for semivolatile constituents (B.P. $\geq$ 100°C). Of the two volatile sampling procedures, the majority of the results indicated that the VOST protocol was more reliable, i.e., less contamination, lower blank values. Gas chromatography/mass spectrometry (GC/MS) was used to resolve and identify organic constituents from the various samples.

A list of "target compounds" was not explicitly reported for 8 of the 9 studies. QA/QC analyses of the 8 studies reviewed in the MRI report[17] (cf. Tables 3.3 and 3.4) indicated that at least 17 volatile and 34 semivolatile organic compounds were quantifiable with generally good relative precision using the above techniques. The lowest molecular weight compound analyzable was benzene, M.W. = 78.1 g/mole, while the heaviest compound analyzable was octachlorocyclopentene, M.W. = 343.7 g/mole. In the absence of specific "target" lists, it appeared that a significant number of potentially stable volatile and semivolatile PIC classes were apparently not amenable to sampling and analysis at trace levels. They included singly-substituted halomethanes, the lower halogenated alkanes and olefins ($> C_2$), conjugated olefins and alkynes, halogenated benzenes (excluding chlorine), halogenated naphthalenes, halogenated biphenyls, and other multiple-ring compounds that may or may not contain halogen substituents.

Table 3.5 presents a list of quantifiable target compounds from the Dow study.[67] The lowest molecular weight compound analyzable was chloromethane, M.W. = 50.5 g/mole, while the heaviest compound analyzable was tetrachloroethene, M.W. = 165.8 g/mole. Although this list of target compounds represents a much more thorough characterization of the effluent compared to the other incinerator studies, there are still several potentially stable volatile and semivolatile PIC classes which were apparently

TABLE 3.3

Comparison of External Quality Assurance Relative Error Results for Volatile Organic Compounds

	External Audits	
	No. of Samples	% of samples w/ relative error ≤ 30%
Chloroform	83	100
Carbon tetrachloride	83	95
Trichloroethene	83	99
Benzene	83	98
Tetrachloroethane	29	100
Toluene	83	98
Methylene chloride	68	94
1,1,1-Trichloroethane	38	100
3,4-Dichloro-1-butene	8	88
Tetrachloroethene	68	100
Chlorobenzene	33	97
Bromodichloromethane	24	100
cis-1,4 Dichloro-2-butene	4	100
Bromoform	25	80
Methylene bromide	13	100
Bromochloromethane	13	100
Dibromochloromethane	13	100

TABLE 3.4

Comparison of External Quality Assurance Relative Error Results for Semivolatile Organic Compounds

	External Audits	
	No of Samples	% of samples w/relative error ≤ 30%
Phenol	19	84
Naphthalene	39	97
Hexachlorobenzene	25	100
Bis(2-ethylhexyl)phthalate	38	74
m-Dichlorobenzene	12	100
p-Dichlorobenzene	12	100
2,4-Dimethylphenol	11	73
1,2,4-Trichlorobenzene	10	100
Diethyl phthalate	4	100
Aniline	3	100
Nitrobenzene	3	100
o-Nitrophenol	3	100
2-Nitrotoluene	3	100
2-Aminophenol	2	50
Quinoline	3	100
4-Aminophenol	1	100
m-Dinitrobenzene	3	100
p-Nitrophenol	3	100
Isophorone	2	100
Dodecanol	2	100
Butylbenzyl phthalate	2	50
3-4-Dichloro-1-butene	7	100
Trans 1,4-dichloro-2-butene	9	100
o-Chlorotoluene	9	100
Benzyl chloride	9	100
Hexachloroethane	9	100
Methylbenzyl chloride	9	89
Tetrachlorobutene	9	100
p-Chlorophenol	9	78
Hexachlorobutadiene	8	100
Hexachloropentadiene	8	100
Octachlorocyclopentene	8	100
Dibutyl phthalate	8	100
Chlordane	8	100

TABLE 3.5

Compilation of all Target Compounds from Dow Incinerator Study

Volatiles:

Chloromethane
Dimethyl ether
Methyl bromide
Vinyl chloride
Methylene chloride
Acetone
Dichlorodifluoromethane
Chloropropene
Trichlorofluoromethane
1,1-Dichloroethylene
Chloroform
1,2-Dichloroethane
1,1,1-Trichloroethane
Carbon Tetrachloride-POHC
Dichlorobromoethane
Dichloroacetonitrile
Benzene
Chlorodibromoethane
2-Chloro-ethyl-vinyl-ether
Bromoform
1,1,2,2-Tetrachloroethylene
Propadiene
n-Butane
1-Butene
Bromochloromethane
Toluene
Chlorobenzene
Acetonitrile
Ethylbenzene

Semivolatiles:

Tetrahydrofuran
n-Pentane
1,3-Pentadiene
Pentanediol
Pentene
Hexene
Iso-octane
n-Octane
Octene

not amenable to sampling and trace analysis. They include the lower halogenated olefins (> C_2), conjugated olefins and alkynes, the higher chlorinated benzenes, halogenated naphthalenes, halogenated biphenyls, and other multiple-ring compounds that may or may not contain halogen substituents.

Compared to the incinerator sources, the four full-scale boiler emission sources represented a narrower range of system designs, types of waste streams, and combustion conditions.[71] Furthermore, because of a more thorough attempt to characterize the effluent, emissions data from the boiler tests, although more limited, is considered to be more representative of the actual emissions from full-scale facilities (excluding the Dow study).

Emissions data considered in this analysis were all generated with a firetube or modified firetube boiler.[71] With the exception of Site G and the baseline runs, all tests were conducted with auxiliary fuel (No. 6 fuel oil or natural gas) co-fired with a hazardous waste stream. Waste streams included mixtures of organic solvents containing chlorinated hydrocarbons (CHCs) or residual oils spiked with CHCs. For the Site G experiments, a mixture of liquid chlorinated hydrocarbons (heating value ~ 21,500 kJ/kg) was used as the fuel. Chloride content (wt %) varied from ~ 0 to ~ 22% in Sites D, E, and F. Much higher values (~ 42 to ~ 45%) were encountered in the Site G tests. Heat input varied from ~ 18 MBtu/hr for Site G, to a range of ~ 50 to ~ 100 MBtu/hr for Sites D and E. Values for Site F ranged from ~ 33 to ~ 37 MBtu/hr.

Table 3.6 summarizes the range of combustion conditions encountered in the four boiler studies. For similar reasons, this data should be treated with the same degree of caution as suggested for the incinerator data. Operating conditions during the tests were those selected by the various plants as their normal, steady state conditions. In general, existing operating problems were corrected before emissions data was collected. Effects of various failure modes and poor combustion conditions on emission rates were not studied.

TABLE 3.6

Range of Combustion Parameters - Boilers

Temperature, °C[1]: 1300 - 1590

Residence time, s[2]: 0.3 - 2.0

Oxygen concentration, %[3]: 5.1 - 8.7

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[1] Estimated
[2] Estimated
[3] Stack measurement, dry basis

Volatile organic emission samples were collected using VOST, while semivolatile organic emission samples were collected using MM5. GC/MS was used to resolve and identify organic constituents from the various samples.

A list of quantifiable "target compounds" is given in Table 3.7. The lowest molecular weight compound analyzable was chloromethane M.W. = 50.5 g/mole, while the heaviest compound analyzable was di-n-octylphthalate, M.W. = 390.5 g/mole. Although this list of target compounds represents a much more thorough characterization of the effluent compared to the incinerator studies, there are still several potentially stable volatile and semivolatile PIC classes which were apparently not amenable to sampling and analysis. They include, conjugated olefins and alkynes, halogenated naphthalenes, halogenated biphenyls, and other multiple-ring compounds that may or may not contain halogen substituents.

Cement kiln emission sources included two Acurex studies (Site I and II)[76] and two other studies by General Portland, Inc.[81] and San Juan Cement Company.[82] It is difficult to compare the overall quality of the waste combustion and sampling and analysis protocols of these systems to the previously reviewed incinerator and boiler sources because of the limited information available. As discussed in detail below, the level of characterization of the effluent was generally very limited. This was particularly the case for the San Juan Cement Company study, where volatile PIC emissions were apparently not even measured.

Emissions data considered in this analysis were all generated with either an aggregate kiln (Site II and General Portland) or rotary kiln dryer (Site I). At General Portland, runs were conducted in the absence of waste (coal combustion) and with two concentrations of chlorinated hydrocarbon waste (~1 and ~4 wt% Cl) co-fired with coal. Waste streams burned at Site I included waste oils and waste solvents containing chlorinated hydrocarbons (<1% Cl); waste streams burned at Site II included liquid waste containing chlorinated hydrocarbons (~2% Cl). Fuel was not co-fired with waste at the Site I facility. Pulverized coal was co-fired with waste for 2 of the 4 tests conducted at the Site II facility, however, baseline coal combustion tests were not conducted. Heat input varied from ~39-40 MJ/kg for Site I to

TABLE 3.7

TARGET COMPOUNDS FOR SITE D,E,F, AND G BOILER STUDIES AND THEIR DETECTION LIMITS

Volatiles:[a]

- Chloromethane
- Dichloromethane
- Chloroform
- Tetrachloromethane
- 1,1-Dichloroethane
- 1,2-Dichloroethane
- 1,1,1-Trichloroethane
- 1,1,2-Trichloroethane
- 1,1,1,2-Tetrachloroethane
- 1,1,2,2-Tetrachloroethane
- 1,2-Dichloropropane
- Hexachlorocyclohexane
- Chloroethylene
- 1,1-Dichloroethylene
- 1,2-Dichloroethylene
- Trichloroethylene
- Tetrachloroethylene
- Allyl chloride
- 1,3-Dichloropropene
- Chloroprene
- Ethylene oxide
- Propylene oxide
- 2-Chloroethyl vinyl ether
- Acetaldehyde
- Acrolein
- Acrylonitrile
- Benzene
- Toluene
- Ethyl benzene
- o-Xylene
- m-Xylene
- p-Xylene
- Chlorobenzene

[a]Detection limits in the range of 1 to 5 ng/l of gas samples.

Semivolatiles:[a]

Acid Compounds

- 2,4,6-Trichlorophenol(5)
- p-Chloro-m-cresol (5)
- 2-Chlorophenol (5)
- 2,4-Dichlorophenol (5)
- 2,4-dimethylphenol (5)
- 2-Nitrophenol (5)
- 4-Nitrophenol (20)
- 2,4-Dinitrophenol (20)
- 4,6-Dinitrophenol (20)
- Pentachlorophenol (5)
- Phenol (1)

Base Neutral Compounds

- 1,2,4-Trichlorobenzene (1)
- 1,2-Dichlorobenzene (1)
- 1,2-Diphenylhydrazine (1) (as azobenzene)
- 1,3-Dichlorobenzene (1)
- 1,4-Dichlorobenzene (1)
- 2,4-Dinitrotoluene (1)
- 2,6-Dinitrotoluene (1)
- 2-Chloronaphthalane (1)
- Benzo(c)phenanthrene (40)
- bis(2-Chloroethyl)ether (1)
- bis(2-Chloroethoxy)methane (1)
- bis(2-Chloroisopropyl)ether (1)
- bis(2-Ethylhexyl)phthalate (1)
- Butyl benzyl phthalate (1)
- Chrysene (1)
- Di-n-butyl phthalate (1)
- Di-n-octyl phthalate (1)

TABLE 3.7 (Continued)

TARGET COMPOUNDS FOR SITE D,E,F, AND G BOILER STUDIES AND THEIR DETECTION LIMITS

Base Neutral Compounds

3,3′-Dichlorobenzidine (5)
3-Methyl cholanthrene (40)
4-Bromophenyl phenyl ether(1)
4-Chlorophenyl phenyl ether(1)
7,12-Dimethyl benz(a)anthracene(40)
N-Nitrosodi-n-propylamine (5)
N-Nitrosodimethylamine (NA)
N-Nitrosodiphenylamine (1)
Acenaphthene (1)
Acenaphthylene (1)
Anthracene (1)
Benzo(ghi)perylene (5)
Benzidine (20)
Benzo(b)fluoranthene (1)
Benzo(k)fluoranthene (1)
Benzo(a)anthracene (1)
Benzo(a)pyrene (1)
Dibenzo(a,h)anthracene (5)
Dibenzo(c,g)carbazole (40)
Diethyl phthalate (1)
Dimethyl phthalate (1)
Fluoroanthene (1)
Fluorene (1)
Hexachlorobenzene (1)
Hexachlorobutadiene (1)
Hexachlorocyclopentadiene (1)
Hexachloroethane (1)
Indeno(1,2,3-cd)pyrene (5)
Isophorone (1)
Naphthalene (1)
Nitrobenzene (1)
Perylene (40)
Phenanthrene (1)
Pyrene (1)

[a] Detection limits (ng/µl) in parenthesis adjacent to compound.

27-31 MJ/kg for Site II. Values for the General Portland study were not reported.

Volatile organic emission samples were collected using VOST, while semivolatile organic emission samples were collected using MM5. GC/MS was used to resolve and identify organic constituents from the various samples. A list of quantifiable "target compounds" for the Site I and Site II tests is given in Table 3.8. The lowest molecular weight compound analyzable was chloromethane M.W. = 50.5 g/mole, while the heaviest compound analyzable was di-n-octyl phthalate, M.W. = 390.5 g/mole. Although this list of target compounds represents a much more thorough characterization of the effluent compared to the incinerator studies, there are still several potentially stable volatile and semivolatile PIC classes which were apparently not amenable to sampling and analysis. They include conjugated olefins and alkynes, the higher chlorinated benzenes (excluding HCB), halogenated naphthalens, halogenated biphenyls, and other multiple-ring compounds that may or may not contain halogen substituents.

It was nearly impossible to assess the quality of the emissions data from the General Portland studies because a list of "target compounds" were not reported. QA audit results for the VOST sampling and analysis indicated that volatile compounds including CCl_4, $CHCl_3$, C_2Cl_4, C_2H_3Cl, and C_6H_6 could be quantified. It was also stated in the body of the report that dichloroethane isomers and C_2HCl_3 could also be quantified. This is obviously a very small percentage of potentially stable PICs which could be emitted from such a system. Information about MM5 QA was not reported.

Full-Scale Emissions Analyses

Tables 3.9 - 3.11 presents a summary of the average relative magnitudes of total organic PICs versus chlorinated PICs (CLPICs) when normalized to input POHC and input chlorinated POHC concentrations, respectively. Average relative magnitudes of these parameters normalized to the total number of tests conducted are depicted in Figs. 3.1 and 3.2. For the 9 incinerators evaluated (cf. Table 3.9), with the exception of the results of the Dow Chemical incinerator tests, the data indicate that %PIC and %CLPIC emissions

TABLE 3.8

TARGET COMPOUNDS FOR SITE I AND SITE II KILN STUDIES AND THEIR DETECTION LIMITS

Volatiles:[a]

- Chloromethane
- Dichloroform
- Chloroform
- Tetrachloromethane
- Chloroethane
- 1,1-Dichloroethane
- 1,2-Dichloroethane
- 1,1,1-Trichloroethane
- 1,1,2-Trichloroethane
- 1,1,2,2-Tetrachloroethane
- 1,2-Dichloropropane
- Hexachlorocyclohexane
- Vinyl chloride
- 1,1-Dichloroethylene
- 1,2-Dichloroethylene
- Trichloroethylene
- Tetrachloroethylene
- Allyl chloride
- 1,3-Dichloropropene
- Chloroprene
- Ethylene oxide
- Propylene oxide
- Ethylene oxide
- Propylene oxide
- Epichlorohydrin
- 2-Chloroethyl vinyl ether
- Acetaldehyde
- Acrolein
- Acrylonitrile
- Benzene
- Toluene
- Ethyl benzene
- o-Xylene
- m-Xylene
- p-Xylene
- Chlorobenzene

[a]Detection limits not specified.

Semivolatiles:[a]

Acid Compounds

- 2,4,6-Trichlorophenol (5)
- p-Chloro-m-cresol (5)
- 2-Chlorophenol (5)
- 2,4-Dichlorophenol (5)
- 2,4-dimethylphenol (5)
- 2-Nitrophenol (5)
- 4-Nitrophenol (20)
- 2,4-Dinitrophenol (20)
- 4,6-Dinitrophenol (20)
- Pentachlorophenol (5)

Base Neutral Compounds

- 1,2,4-Trichlorobenzene (1)
- 1,2-Dichlorobenzene (1)
- 1,2-Diphenylhydrazine (1) (as azobenzene)
- 1,3-Dichlorobenzene (1)
- 1,4-Dichlorobenzene (1)
- 2,4-Dinitrotoluene (1)
- 2,6-Dinitrotoluene (1)
- 2-Chloronaphthalene (1)
- Benzo(c)phenanthrene (40)
- bis(2-Chloroethoxy)methane (1)
- bis(2-Chloroethyl)ether (1)
- bis(2-Chloroisopropyl)ether (1)
- bis(2-Ethylhexyl)phthalate (1)
- Butyl benzyl phthalate (1)
- Chrysene (1)
- Di-n-butyl phthalate (1)
- Di-n-octyl phthalate (1)

TABLE 3.8 (Continued)

TARGET COMPOUNDS FOR SITE I AND SITE II KILN STUDIES AND THEIR DETECTION LIMITS

3,3′-Dichlorobenzidine (5)
3-Methyl cholanthrene (40)
4-Bromophenyl phenyl ether (1)
4-Chlorophenyl phenyl ether (1)
7,12-Dimethyl benz(a)anthracene (40)
N-Nitrosodi-n-propylamine (5)
N-Nitrosodimethylamine (NA)
N-Nitrosodiphenylamine (1)
Acenaphthene (1)
Acenaphthylene (1)
Anthracene (1)
Benzo(ghi)perylene (5)
Benzidine (20)
Benzo(b)fluoranthene (1)
Benzo(k)fluoranthene (1)
Benzo(a)anthracene (1)
Benzo(a)pyrene (1)
Dibenzo(a,h)anthracene (5)
Dibenzo(c,g)carbazole (40)
Diethyl phthalate (1)
Dimethyl phthalate (1)
Fluoroanthene (1)
Fluorene (1)
Hexachlorobenzene (1)
Hexachlorobutadiene (1)
Hexachlorocyclopentadiene (1)
Hexachloroethane (1)
Indeno(1,2,3-cd)pyrene (5)
Isophorone (1)
Naphthalene (1)
Nitrobenzene (1)
Perylene (40)
Phenanthrene (1)
Pyrene (1)

[a] Detection limits (ng/μl) given in parenthesis adjacent to compound.

TABLE 3.9

% PIC EMISSIONS - INCINERATOR TESTS

	American Cyanamid %PIC Emissions (per POHC Input)	%ClPIC Emissions (per ClPOHC Input)	DuPont %PIC Emissions (per POHC Input)	%CLPIC Emissions (per CLPOHC Input)	Mitchell %PIC Emissions (per POHC Input)	%CLPIC Emissions (per CLPOHC Input)
	Gas bags/semivolatiles:		Gas bags/semivolatiles:		Gas bags/semivolatiles:	
Run 1	NA	NA	1.89E-03	1.87E-04	4.79E-04	3.84E-03
Run 2	1.66E-03	Undefined [1]	6.94E-04	6.23E-06	1.12E-03	3.56E-03
Run 3	6.60E-04	Undefined	1.79E-03	1.14E-04	8.70E-04	1.79E-03
Run 4	1.26E-02	Undefined			8.21E-04	8.29E-03
Run 5	9.53E-04	Undefined				
	Vost/semivolatiles:		Fast Vost/semivolatiles:		Fast Vost/semivolatiles:	
Run 1	NA	NA	7.10E-06	1.52E-04	6.70E-05	4.60E-04
Run 2	1.78E-03	Undefined	1.41E-03	6.77E-07	7.21E-04	1.13E-03
Run 3	2.29E-04	Undefined	6.65E-04	8.02E-06	3.39E-04	6.97E-04
Run 4	1.11E-02	Undefined				
			Slow Vost/semivolatiles:		Slow Vost/semivolatiles:	
Run 1			4.95E-06	7.95E-06	7.02E-05	6.67E-04
Run 2			5.35E-04	4.44E-06	1.84E-03	6.83E-03
Run 3			7.96E-04	6.86E-06	6.61E-03	1.15E-02

	TWI (optimum) %PIC Emissions (per POHC Input)	%CLPIC Emissions (per CLPOHC Input)	Dow Chemical %PIC Emissions (per POHC Input)	%CLPIC Emissions (per CLPOHC Input)	Upjohn %PIC Emissions (per POHC Input)	%CLPIC Emissions (per CLPOHC Input)
	Gas bags/semivolatiles:		Vost + gas bag:		Gas bags + semivolatiles	
Run 1	NA	NA	6.79E-02	6.64E-02	3.77E-06	3.90E-03
Run 2	2.04E-04	NA	6.39E-02	6.19E-02	1.31E-03	1.06E-03
Run 3	6.11E-06	NA	4.91E-02	4.85E-02	1.24E-03	1.32E-03
Run 4	1.66E-03	1.81E-03	6.66E-02	6.39E-02		
Run 5			6.41E-02	6.18E-02		
Run 6			6.63E-02	6.37E-02		
	Fast Vost/semivolatiles:				Vost + semivolatiles	
Run 1	2.36E-04	7.03E-06			6.74E-03	4.99E-03
Run 2	6.50E-04	1.17E-03			1.61E-03	7.51E-04
Run 3	1.06E-03	2.36E-03			2.29E-03	1.23E-03
Run 4	5.36E-04	1.44E-03				
	Slow Vost/semivolatiles:					
Run 1	7.33E-06	5.95E-04				
Run 2	9.37E-04	2.33E-03				
Run 3	8.40E-04	2.25E-03				

	Ross %PIC Emissions (per POHC Input)	%CLPIC Emissions (per CLPOHC Input)	Zapata %PIC Emissions (per POHC Input)	%CLPIC Emissions (per CLPOHC Input)	TWI (failure) %PIC Emissions (per POHC Input)	%CLPIC Emissions (per CLPOHC Input)
	Gas bags/semivolatiles:		Gas bags:		Slow Vost/semivolatiles:	
Run 1	2.31E-03	4.20E-03	1.34E-04	1.88E-05	2.61E-05	1.46E-03
Run 2	1.37E-03	2.61E-03	4.66E-05	4.16E-04	2.62E-05	2.16E-03
Run 3	1.53E-03	3.06E-03	8.44E-04	3.02E-04	1.91E-04	0.00E+00
Run 4			3.25E-05	1.09E-05	4.80E-05	6.61E-04
	Vost/semivolatiles:		Vost:			
Run 1	8.31E-04	7.07E-04	3.11E-06	3.11E-04		
Run 2	1.34E-03	1.29E-03	1.29E-03	3.99E-04		
Run 3	8.84E-04	9.64E-04				

Note:
1. There was no ClPOHCs in the waste feed above a concentration of 100 ppm by weight.

TABLE 3.10

% PIC EMISSIONS - BOILER TESTS

	Acurex Site D		Acurex Site E	
	%PIC Emissions (per POHC input)	%CLPIC Emissions (per CLPOHC input)	%PIC Emissions (per POHC input)	%CLPIC Emissions (per CLPOHC input)
Run 1	Undefined [1]	Undefined	Undefined	Undefined
Run 2	6.38E-03	4.51E-03	7.40E-02	NA
Run 3	1.09E-02	7.85E-03	2.00E-01	2.94E-01
Run 4	3.90E-02	3.40E-02	1.10E-02	4.13E-03
Run 5	1.65E-03	4.11E-02	1.07E-02	5.78E-03
Run 6	1.16E-03	2.80E-02	1.15E-02	6.30E-03
Run 7	2.66E-04	4.43E-03	1.44E-01	1.51E-01
Run 8			5.20E-02	4.88E-02
Run 9			3.67E-03	

	Acurex Site F		Acurex Site G	
	%PIC Emissions (per POHC input)	%CLPIC Emissions (per CLPOHC input)	%PIC Emissions (per POHC input)	%CLPIC Emissions (per CLPOHC input)
Run 1	Undefined	Undefined	4.69E-03	2.98E-03
Run 2	7.17E-01	6.11E-01	4.41E-03	2.81E-03
Run 3	5.37E-01	5.59E-01	6.24E-04	3.61E-04
Run 4	5.05E-02	4.00E-02		

Footnotes:

1. There was no waste feed to boilers in run 1 at sites D, E, and F.

TABLE 3.11

% PIC EMISSIONS - KILN TESTS

	Acurex Site I		Acurex Site II	
	%PIC Emissions (per POHC input)	%CLPIC Emissions (per CLPOHC input)	%PIC Emissions (per POHC input)	%CLPIC Emissions (per CLPOHC input)
Run 1	3.74E-02	4.45E-02	1.17E-03	4.22E-03
Run 2	7.90E-03	9.39E-03	3.49E-03	1.22E-02
Run 3	2.82E-03	3.35E-03	3.63E-03	1.33E-02
Run 4			5.74E-03	2.12E-02

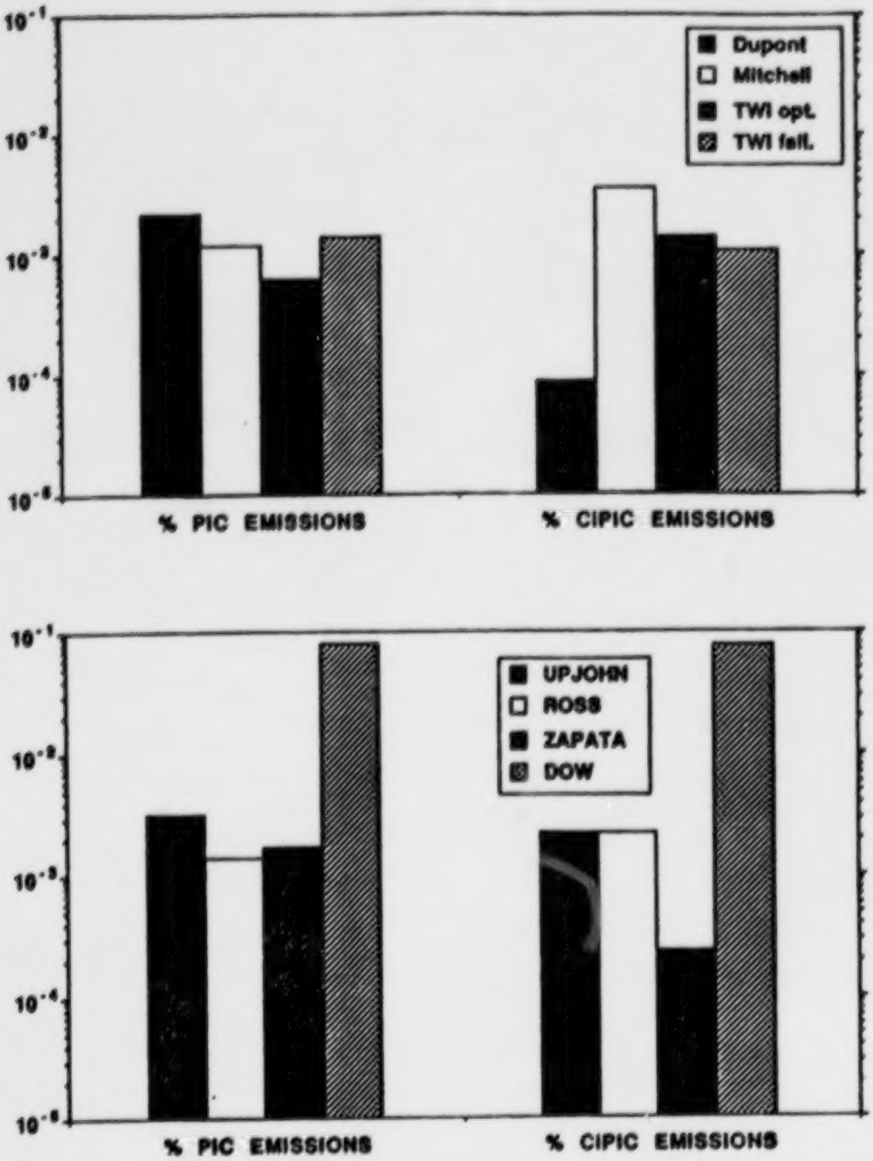

Figure 3.1. Average relative magnitudes of %PIC and %CLPIC emissions from full-scale incinerators. Data obtained from Table 3.9 by averaging over the total number of tests conducted.

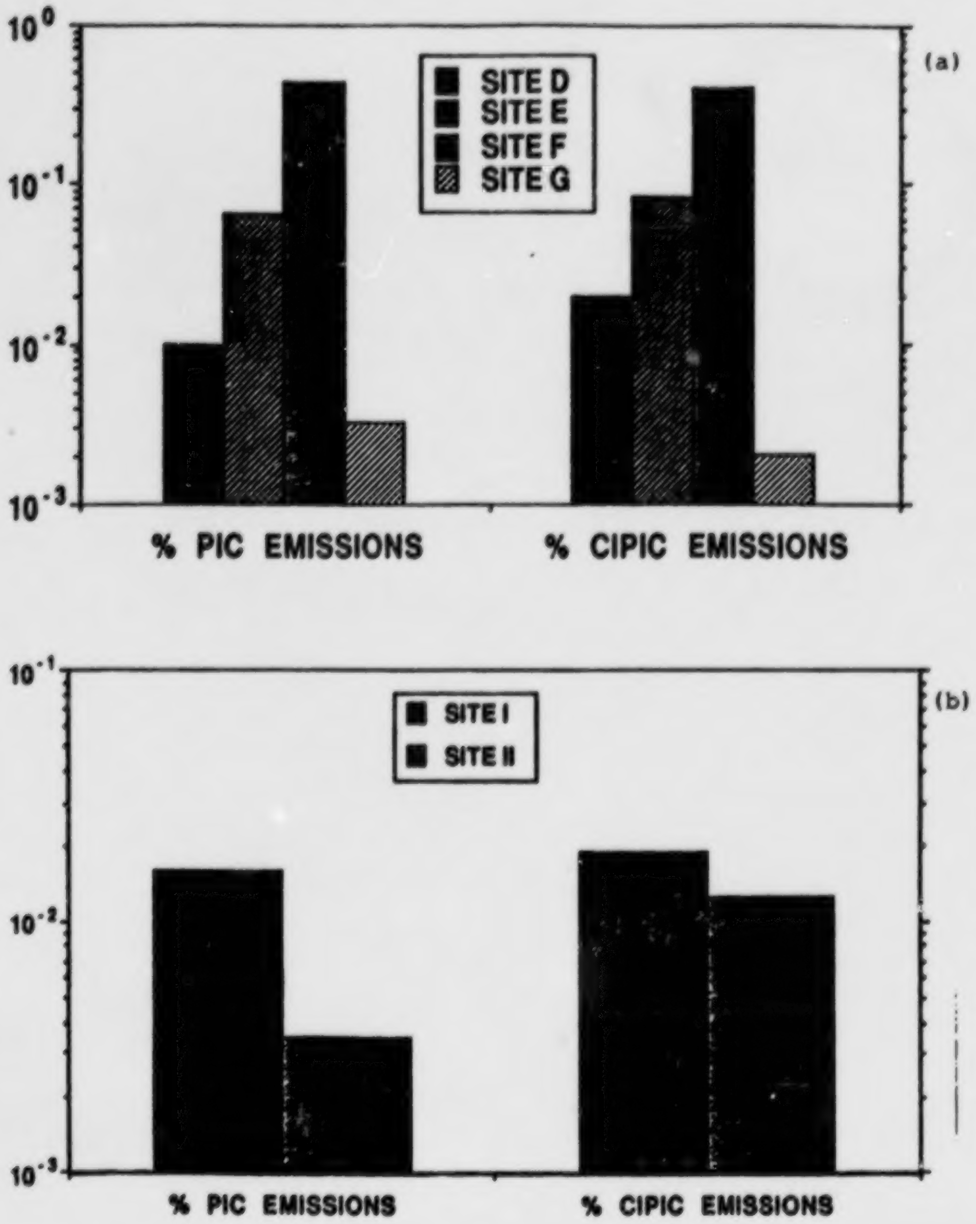

Figure 3.2. Average relative magnitudes of %PIC and %CLPIC emissions from full-scale boilers (a) and kilns (b). Data obtained from Tables 3.10 and 3.11 by averaging over the total number of tests conducted.

were nearly always less than 0.01%. In contrast to the incinerator data, 3 of the 4 boilers evaluated produced %PIC and %CLPIC emissions in excess of 0.01% (cf. Table 3.10). More specifically, 60% of tests with POHCs co-fired with fuel produced %PIC emissions greater than 0.01% while 50% of tests with CLPOHCs co-fired with fuel produced %CLPIC emissions greater than 0.01%. Evaluation of the cement kiln data (cf. Table 3.11) revealed that two of the sources, General Portland, Inc. and San Juan Cement Company, did not report POHC feedrates and thus were not available for characterization. Of the two remaining studies, the results indicated that %PIC emissions were greater than 0.01% in only 1 of 7 studies while %CLPIC emissions were greater than 0.01% in 4 of 7 studies. The greater level of CLPIC versus PIC emissions was not generally observed in the analysis of the other thermal disposal data.

To the degree that organic emissions are fully characterized from these facilities, this analysis suggests that PIC and CLPIC emissions are not emitted in greater quantities than to measured POHC emissions in a majority of hazardous waste incinerators. However, it must be emphasized that the primary impetus in conducting the 8 incinerator tests (excluding the Dow Chemical study) was demonstration of ≥ 99.99% destruction and removal efficiency (DRE) for the waste surrogates. Although this objective was clearly demonstrated, the total number of volatile and semivolatile organic PICs which were quantified in the stack effluent were not reported. In contrast to these 8 studies, the Dow Chemical incinerator study represented a more thorough attempt to characterize organic emissions from a full-scale incinerator. The level of PICs in the effluent were found to range from approximately one to three orders of magnitude greater than those detected in the other incinerator studies. This was due to the combined effects of the following: 1) enhanced emission rates of chloroform, benzene, and toluene, and 2) improved sampling and analysis technique for chloromethane which accounted for 25-50% of the observed emissions. Furthermore, the level of CLPICs in the effluent were found to range from approximately one to five orders of magnitude greater than those detected in the other incinerator studies. Although one must be cautious in extrapolating the results of a single incinerator study, the large disparity in the respective analyses nonetheless suggests that PIC emissions in the other 8 studies were not fully quantified.

In contrast to the majority of the incinerator data, %PIC emissions from the full-scale boiler effluent were as large as 0.72%. Similarly, %CLPIC emissions from these facilities were as large as 0.61%. Although the degree of characterization of effluent emissions from these tests was much greater than for a majority of the incinerator studies, emission of stable PICs from the combustion of fuel co-fired with the waste has been proposed as the primary explanation for the greater level of emissions from these facilities. Inspection of the relative magnitude of %PIC emissions normalized to the total fuel and waste input provides a test of this hypothesis. Table 3.12 and Fig. 3.3 presents %PIC emissions normalized to total feed (fuel and waste) input; % waste heat input is also shown indicative of the degree of co-firing of fuel and waste. Although the type and quality of data from each source varies greatly, the results in Table 3.12 indicate that the fuel does account for a measurable level of PIC emissions. More importantly, however, the data also indicates that in 76% of the tests, PICs emitted from combustion of waste co-fired with fuel were greater than baseline levels. Furthermore, PICs emitted from combustion of waste co-fired with fuel were more than a factor of 2 greater than baseline levels in 47% of the tests. Inspection of the effect of fuel versus fuel/waste combustion on CLPIC emissions indicated that greater emissions were evident under fuel/waste conditions in 88% of the tests. CLPIC emissions were only observed in 1 of the 3 facilities (Site F) for which baseline tests were conducted.

This analysis does not repudiate the claim that fuel combustion contributes to the level of PIC emitted from full-scale boilers. This analysis does, however, indicate that the greater level of PIC emissions from full-scale boilers relative to incinerators is clearly related to additional factors besides the presence of fuel. These factors must include the degree of analytical measurement of the effluent gases in addition to other factors related to differences in waste feed composition, e.g., concentration of PIC precursors present, and differences in design and operation of these two thermal disposal systems, i.e., variability of combustion conditions.

TABLE 3.12

% PIC EMISSIONS PER FUEL/WASTE INPUT - BOILER TESTS

	Acurex Site D Waste Heat Input (%)	% PIC Emissions (per fuel/waste input)	Acurex Site E Waste Heat Input (%)	% PIC Emissions (per fuel/waste input)
Baseline	0	3.46E-04	0	8.62E-04
Run 2	30	8.07E-04	22	8.95E-04
Run 3	29	6.06E-04	28	1.02E-02
Run 4	18	1.19E-03	28	5.87E-04
Run 5	48	9.57E-04	28	6.45E-04
Run 6	46	6.80E-04	43	9.34E-04
Run 7	48	1.56E-04	19	6.56E-03
Run 8			33	3.05E-03
Run 9			56	2.32E-03

	Acurex Site F Waste Heat Input (%)	% PIC Emissions (per fuel/waste input)
Baseline	0	5.54E-03
Run 2	9	3.81E-03
Run 3	10	8.54E-03
Run 4	9	6.34E-04

TABLE 3.13

% PIC EMISSIONS PER FUEL/WASTE INPUT - KILN TEST

Acurex Site II

	Waste Heat Input (%)	% PIC Emissions (per fuel/waste input)
Run 1	59	5.88E-05
Run 2	47	1.75E-04
Run 3	100	2.28E-04
Run 4	100	3.54E-04

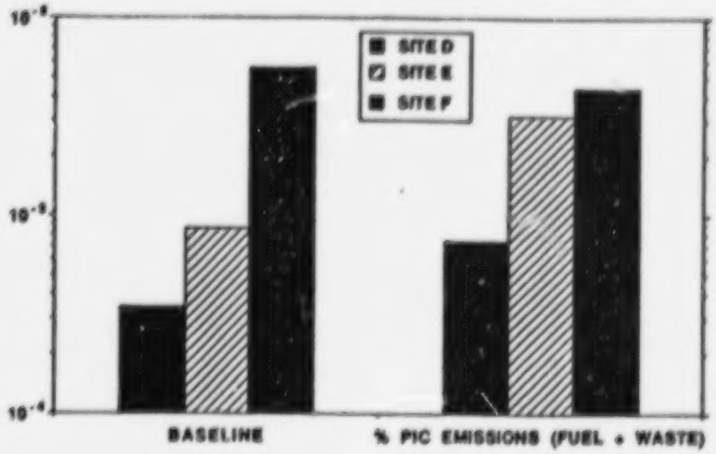

Figure 3.3. Average relative magnitudes of %PIC emissions from full-scale boilers. Data obtained from Table 3.12 by averaging over the total number of tests conducted. Baseline data represent fuel combustion only.

Analogous to the boiler results, PIC and CLPIC emissions from cement kilns were generally greater than for incinerators. Although the database is extremely sparse, a similar analysis of the relative magnitude of PIC emissions generated solely from burning waste versus co-fired fuel and waste (cf. Table 3.13) indicated that the presence of the fuel was once again not solely responsible for the increase in the level of PIC emissions relative to pure waste combustion. Further support of this finding was demonstrated in the General Portland study where an approximately 1 order of magnitude increase in PIC emissions was observed when burning a waste stream containing ~4% chlorine versus baseline fuel combustion (see Appendix C).

Tables 3.14-3.16 present specific PIC emissions data calculated from the raw data available from the 9 hazardous waste incinerators, 4 boilers, and 4 cement kilns, respectively. For each compound, frequency of occurrence, arithmetic mean emission rate, and geometric mean emission rate are presented. In calculation of the arithmetic and geometric mean emission rates, only values greater than analytical detection limits were considered, i.e., detection limit values were not assigned a numerical value.

Inspection of the full-scale incinerator data (cf. Table 3.14) indicates that chloroform, benzene, tetrachloroethene, toluene, carbon tetrachloride, methylene chloride, 1,1,1-trichloroethane, chlorobenzene, and naphthalene are the most prevalent PICs, emitted in at least 75% of all tests. It should be noted that occurrence frequency in this context excludes the presence of the compound in waste feed as a POHC. Of these compounds, chloroform, methylene chloride, benzene, toluene, and naphthalene exhibited largest emission rates ($\geq$ 1000 μg/min). The greater values of arithmetic versus geometric mean emission rates for many of these compounds indicates the absence of a normal distribution of emission data, i.e., the distribution is skewed towards larger emission rates. Considering the scatter in the data, the geometric mean emission rate is a more representative measure of the actual emission rate for these compounds.

Further inspection of Table 3.14 indicates that chloromethane, methylene bromide, bromomethane, bromoform, bromodichloromethane, dibromochloromethane and bromochloromethane also exhibited emission rates

TABLE 3.14

SPECIFIC PIC EMISSIONS - INCINERATOR TESTS

VOLATILE PICS

Compound	Frequency of Occurrence [1]	Arithmetic Mean Emission Rate [2] (ug/min)	Geometric Mean Emission Rate [3] (ug/min)	Formation Mechanism
Benzene	6 / 6	38396.8	6756.5	Radical-molecule
Chloroform	6 / 6	31616.3	2549.5	Association
Toluene	3 / 3	4198.7	1981.7	Radical-molecule
Carbon tetrachloride	1 / 1	126.3	120.4	Association
Tetrachloroethene	4 / 4	378.0	107.1	Radical-molecule
Chlorobenzene	4 / 5	674.0	494.8	Radical-molecule
1,1,1-Trichloroethane	4 / 5	520.3	84.3	Association
Methylene chloride	3 / 4	11707.7	1623.0	Radical-molecule
Bromodichloromethane	6 / 9	4794.7	2295.5	Association
Dibromochloromethane	6 / 9	1592.8	1059.6	Association
Bromoform	5 / 9	8254.8	2419.3	Association
Trichloroethene	1 / 2	762.0	721.1	Radical-molecule
Bromochloromethane	3 / 9	7334.0	1733.5	Association
Chloromethane	2 / 8	197481.0	161375.0	Radical-molecule
Methyl ethyl ketone	1 / 7	172.0	169.0	Radical-molecule
Methylene bromide	1 / 8	12800.0	12554.0	Association
Bromomethane	1 / 8	2300.0	2291.3	Association
Chloroethene	1 / 9	2405.0	2144.0	Molec. Elim.
1,2-Dichloroethane	1 / 9	1946.0	1510.0	Association

SEMIVOLATILE PICS

Compound	Frequency of Occurrence [1]	Arithmetic Mean Emission Rate [2] (ug/min)	Geometric Mean Emission Rate [3] (ug/min)	Formation Mechanism
Naphthalene	3 / 4	2764.3	1461.2	Radical-molecule
Phenol	2 / 8	4326.5	1633.0	Association
2-Nitrophenol	2 / 8	4971.5	3398.5	Association
2,4,6-Trichlorophenol	1 / 8	5867.0	5867.0	Association
2,4-Dimethylphenol	1 / 8	1600.0	1600.0	Association
Pyrene	1 / 8	1100.0	1100.0	Radical-molecule
2,6-Toluene diisocyanate	1 / 8	200.0	200.0	Radical-molecule
Hexachlorobenzene	1 / 8	24.0	24.0	Radical-molecule
2-Chlorophenol	1 / 8	479.0	479.0	Association
Pentachlorophenol	1 / 8	340.0	340.0	Association
Fluoranthene	1 / 8	700.0	700.0	Radical-molecule

Footnotes:

1. Defined as number of occurrences as PIC divided by total number of possible occurrences as PIC; denominator excludes presence in waste feed.
2. Arithmetic mean emission rate for all sites; individual data (per site) consist of an arithmetic mean based on the number of measurements obtained above detection limits.
3. Geometric mean emission rate for all sites; individual data (per site) consist of geometric mean based on the number of measurements obtained above detection limits.

comparable to or greater than the more frequently observed compounds. There are at least three potential causes for the intermittent emission of these brominated halomethane PICs: 1) they are formed (via true PIC formation) from bromine-containing precursors in the waste or fuel which were not reliably analyzed by full-scale analytical techniques, 2) they are contained in nearly all waste streams yet not reliably analyzed by full-scale analytical techniques, and 3) they are formed by volatile compound stripping from makeup scrubber water. The first and third explanations readily apply to brominated compounds while the second explanation may be applied to certain constituents of both the brominated and chlorinated methane compound classes. The degree to which brominated compounds are either specific to certain waste streams, a contaminant in a large majority of waste streams, or produced by volatile compound stripping from makeup scrubber water cannot be ascertained with the available data.

Section 2 delineated 3 specific PIC formation mechanisms based on an analysis of laboratory-scale PIC formation and destruction behavior. These mechanisms are also listed in Table 3.14 for the specific PICs identified from the incinerator evaluation. For the types of PICs observed, emission mechanisms are divided into three categories, molecular elimination, radical-molecule and radical association reactions. The relative contributions of these three mechanisms to the observed PIC emissions depend on the relative importance of the following parameters: 1) frequency of occurrence and 2) geometric mean emission rate. Considering the former as more significant suggests that 67% of the PICs are emitted by a radical-molecule mechanism. However, based on geometric mean emission rate ($\geq$ 1000 μg/min), the data indicate that both radical-molecule and radical association mechanisms are of equal significance in producing PIC emissions. An equal weighting of these two parameters indicates that 67% of the PICs are emitted by radical-molecule mechanisms (weighted geometric mean emission rate $\geq$ 1000 μg/min). The above analysis excludes brominated halomethane compounds because a significant portion of their mechanism of formation may be due to stripping of scrubber makeup water. Observed phthalate compounds have also been excluded because a significant portion of their mechanism of formation are likely the result of sampling or analytical error or ubiquitous sources, e.g., outgassing of phthalates in plasticizers appearing in laboratories.

Inspection of the full-scale boiler data (cf. Table 3.15) indicates that chloroform, benzene, tetrachloroethene, toluene, methylene chloride, carbon tetrachloride, chloromethane, 1,1,1-trichloroethane, 1,1-dichloroethene, 1,2-dichloroethane, phenol, and naphthalene are the most prevalent PICs, emitted in at least 75% of all tests. Of these compounds, chloroform, benzene, tetrachoroethene, toluene, methylene chloride, carbon tetrachloride, chloromethane, and 1,1,1-trichloroethane exhibited the largest emission rates ($\geq$ 7500 μg/min). Due to the disparity in arithmetic and geometric mean emission rates for many of these compounds, the geometric mean emission rate is considered a more representative measure of the actual emission rate for these compounds.

In contrast to the incinerator data, further inspection of Table 3.15 indicates that fewer halomethane compounds were observed in the stack gases of full-scale boilers. Trichlorofluoromethane, bromoform, dibromochloromethane were the only halomethanes detected, all at emission rates < 7500 μg/min. Emission mechanisms for the specific PICs identified are also listed in Table 3.15. As we observed for the incinerator data, emission mechanisms are divided into three categories, molecular elimination, radical-molecule and radical association reactions. If we follow the same procedure invoked in the incinerator analysis, considering PIC frequency of occurrence as the classification parameter indicates that 55% of the PICs are emitted by a radical-molecule mechanisms. Similarly, based on geometric mean emission rate ($\geq$ 7500 μg/min), the data also indicates that 64% of the PICs are emitted by a radical-association mechanisms.

Inspection of the limited full-scale kiln data (cf. Table 3.16) indicates that chloroform, benzene, methylene chloride, and naphthalene are the most prevalent PICs, emitted in at least 75% of all possible cases. Of these compounds, chloroform, benzene, and methylene chloride exhibited largest emission rates ($\geq$ 1000 μg/min). Due to the disparity in arithmetic and geometric mean emission rates for many of these compounds, the geometric mean emission rate is a more representative measure of the actual emission rate for these compounds. Less frequently observed compounds with high geometric mean emission rates ($\geq$ 1000 μg/min) included chloromethane, chloroethene, tetrachloroethene, and 1,1,2-trichloroethane.

TABLE 3.15

SPECIFIC PIC EMISSIONS - BOILER TESTS

VOLATILE PICS

Compound	Frequency of Occurrence [1]	Arithmetic Mean Emission Rate [2] (ug/min)	Geometric Mean Emission Rate [3] (ug/min)	Formation Mechanism
Methylene chloride	4 / 4	826980.0	96407.9	Radical-molecule
Tetrachloroethene	3 / 3	46788.0	32214.6	Radical-molecule
Chloroform	4 / 4	149850.0	31391.0	Association
Toluene	3 / 3	90700.0	21053.3	Radical-molecule
Carbon tetrachloride	1 / 1	11280.0	10308.0	Association
Benzene	4 / 4	27330.0	10046.5	Radical-molecule
Chloromethane	3 / 4	26120.0	9593.2	Radical-molecule
1,1,1-Trichloroethane	3 / 4	15340.0	8627.8	Association
1,2-Dichloroethane	3 / 4	18380.0	2977.2	Association
1,1-Dichloroethene	3 / 4	4222.0	422.6	Molec. Elim.
Chlorobenzene	2 / 3	8340.0	2732.8	Radical-molecule
Dibromochloromethane	2 / 4	17190.0	5612.7	Association
1,1,2,2-Tetrachloroethane	2 / 4	4560.0	2524.3	Association
Trichloroethene	1 / 2	1320.0	1164.0	Molec. Elim.
1,2-Dichloropropane	2 / 4	1740.0	572.6	Association
Chloroethane	2 / 4	591.0	291.2	Association
Chloroethene	2 / 4	1044.0	233.0	Molec. Elim.
1,1,2-Trichloroethane	1 / 4	6138.0	5508.0	Association
Trichlorofluoromethane	1 / 4	113880.0	4662.0	Association
Bromoform	1 / 4	1320.0	1320.0	Association
t-1,2-Dichloroethene	1 / 4	1008.0	468.0	Molec. Elim.
t-1,3-Dichloropropene	1 / 4	21.0	21.0	Radical-molecule
c-1,3-Dichloropropene	1 / 4	21.0	21.0	Radical-molecule

SEMIVOLATILE PICS

Compound	Frequency of Occurrence [1]	Arithmetic Mean Emission Rate [2] (ug/min)	Geometric Mean Emission Rate [3] (ug/min)	Formation Mechanism
Naphthalene	4 / 4	639.0	364.3	Radical-molecule
Phenol	4 / 4	488.0	262.3	Association
bis(2-chloroisopropyl)ether	2 / 3	2076.0	542.0	Association
2,4,6-Trichlorophenol	2 / 4	729.0	587.9	Association
2,4-Dimethylphenol	2 / 4	1047.0	475.1	Association
bis(2-chloroethyl)ether	1 / 3	4080.0	3930.0	Association
Fluoranthene	1 / 4	180.0	150.0	Radical-molecule
1,3-Dichlorobenzene	1 / 4	510.0	486.0	Radical-molecule
Benzo[a]anthracene	1 / 4	186.0	186.0	Radical-molecule
1,4-Dichlorobenzene	1 / 4	474.0	462.0	Radical-molecule
1-Chlorophenol	1 / 4	534.0	534.0	Association
2,4-Dichlorophenol	1 / 4	318.0	318.0	Association
Acenaphthalene	1 / 4	120.0	120.0	Radical-molecule
Fluorene	1 / 4	49.2	49.2	Radical-molecule
Hexachlorobenzene	1 / 4	324.0	318.0	Radical-molecule

Footnotes:

1. Defined as number of occurrences as PIC divided by total number of possible occurrences as PIC; denominator excludes presence in waste feed.
2. Arithmetic mean emission rate for all sites; individual data (per site) consist of an arithmetic mean based on the number of measurements obtained above detection limits.
3. Geometric mean emission rate for all sites; individual data (per site) consist of geometric mean based on the number of measurements obtained above detection limits.

TABLE 3.16

SPECIFIC PIC EMISSIONS - KILN TESTS

VOLATILE PICS

Compound	Frequency of Occurrence [1]	Arithmetic Mean Emission Rate [2] (ug/min)	Geometric Mean Emission Rate [3] (ug/min)	Formation Mechanism
Benzene	3 / 3	2757266.0	38950.1	Radical-molecule
Chloroform	3 / 3	18567.0	1234.0	Association
Methylene chloride	1 / 1	2670.0	2100.0	Radical-molecule
Carbon tetrachloride	2 / 3	5350.5	638.3	Association
Tetrachloroethene	1 / 2	101100.0	86760.0	Radical-molecule
Chloromethane	2 / 4	17994.0	5726.7	Radical-molecule
Chloroethene	2 / 4	1263.0	1141.7	Molec. Elim.
1,1-Dichloroethene	2 / 4	1731.0	710.6	Radical-molecule
Bromomethane	2 / 4	699.0	568.2	Association
1,1,2-Trichloroethane	1 / 4	7800.0	7680.0	Association
Chloroethane	1 / 4	246.0	246.0	Association
t-1,2-Dichloroethene	1 / 4	60.0	56.4	Molec. Elim.

SEMIVOLATILE PICS

Compound	Frequency of Occurrence [1]	Arithmetic Mean Emission Rate [2] (ug/min)	Geometric Mean Emission Rate [3] (ug/min)	Formation Mechanism
Naphthalene	3 / 4	508.0	406.3	Radical-molecule
Phenol	2 / 4	1617.0	511.9	Association
2-Chlorophenol	1 / 4	720.0	720.0	Association
2,6-Dinitrotoluene	1 / 4	462.0	462.0	Association

Footnotes:

1. Defined as number of occurrences as PIC divided by total number of possible occurrences as PIC; denominator excludes presence in waste feed.
2. Arithmetic mean emission rate for all sites; individual data (per site) consist of an arithmetic mean based on the number of measurements obtained above detection limits.
3. Geometric mean emission rate for all sites; individual data (per site) consist of geometric mean based on the number of measurements obtained above detection limits.

In contrast to the incinerator data yet consistent with the boiler data, further inspection of Table 3.16 indicates that only one brominated compound (bromomethane) was observed in the stack gases of full-scale kilns. This compound was observed in 50% of possible cases with an emission rate ≤ 1000 µg/min. Emission mechanisms for the specific PICs identified are also listed in Table 3.16. If we follow the same procedure invoked in the incinerator and boiler analyses, considering PIC frequency of occurrence as the classification parameter indicates that 75% of the PICs are emitted by radical-molecule mechanisms. Furthermore, based on geometric mean emission rate (≥ 1000 µg/min), the data indicate that 67% of the PICs are emitted by radical-molecule mechanisms. Similarly, an equal weighting of these two parameters indicates that 67% of the PICs are emitted by a radical-molecule mechanism (weighted geometric mean emission rate ≥ 1000 µg/min.).

Pilot-Scale Emissions Analysis

A review of the pilot-scale emission sources revealed that only 3 different studies produced quantitative information regarding organic PIC emissions.[96,97,99] All three of these studies were conducted at the U.S.-EPA Combustion Research Facility. The initial study burned mixtures of fuel (toluene or propane) and chlorinated benzenes in both a rotary kiln and afterburner system.[96] The second and third studies consisted of combustion of a polychlorinated biphenyl mixture (Aroclor 1260)[97] and combustion of a 4-component synthetic organic waste mixture spiked with sulfur hexafluoride.[99] The latter tests were performed using just the liquid injection incineration system.

A summary of the key combustion parameters is given in Table 3.17. A majority of experiments were conducted under near-optimum steady-state conditions. A small number of failure mode experiments were conducted in the course of the chlorinated benzenes combustion studies. As shown in Table 3.18, these tests demonstrated the pronounced effect of temperature on the emission rates of numerous PICs from the rotary kiln. %PIC emissions (normalized to the POHC feed rate) increased by over five orders of magnitude as the temperature was reduced from ~800°C to < 700°C. Emission

TABLE 3.17

RANGE OF COMBUSTION PARAMETERS---PILOT-SCALE STUDIES

Chlorinated Benzene	PCB Study	Synthetic Mixture Study
Avg. Kiln Temp. = 510-871°C	Avg. Prim'y Combustion Chamber Temp. = 1240°C	Avg. Primary Combustion Chamber Temp. = 943-1310°C
Avg. Residence Time (Kiln): NA	Avg. Residence Time (primary & afterburner chamber) = 4.0s	Avg. Residence Time (primary & afterburner chamber) = 4.0s
Avg. Afterburner Temp. = 815-1093°C	Avg. Afterburner Temp. = 1026°C	Avg. Afterburner Temp. = 342-793°C
Avg. Excess Air (Kiln): 6.1-11.7%	Avg. Excess Air (primary & afterburner chamber) = 12%	Avg. Excess Air (primary chamber) = 1.3-9.2%
Avg. Residence Time (Afterburner): 1.05-2.4 s		

TABLE 3.18

EFFECT OF KILN TEMPERATURE ON PIC EMISSIONS - CHLORINATED BENZENE STUDY

Kiln Temperature (°C)	815-788	760-732	704-677
AB Temperature (°C)	1093	1093	1093
C_4Cl_6 (μg/min)	<0.067	<0.067	476
1,2-DCBz (μg/min)	<0.66	<0.66	536
1,3,5-TCBz (μg/min)	<0.29	<0.29	1500
1,2,4-TCBz (μg/min)	210	682	884000
1,2,3,4-TCBz (μg/min)	<0.041	<0.041	7810
Cl_5-Bz (μg/min)	0.505	5.06	57200
Cl_6-Bz (μg/min)	<0.086	<0.086	51300
1,2,3,4-TCNaph (μg/min)	<0.34	<0.34	2980
% PIC Emissions (per POHC input)	1×10^{-6}	8×10^{-6}	1.83×10^{-1}

rates at the exit of the afterburner were insensitive to the rotary kiln temperature changes.

The effects of variation in primary combustion temperature and excess air level on PIC emissions were also studied in the combustion of a 4-component synthetic organic waste mixture spiked with sulfur hexafluoride. As shown in Table 3.19, there was no apparent relationship between temperature (or excess air level) and PIC emissions. This result is in contrast to the earlier chlorinated benzene study. However, this result is not necessarily surprising when one considers the fact that much higher absolute temperatures were used in synthetic mixture combustion study. It is apparent that the temperature (and excess air) envelope studied was much too high (and too fuel-lean) than required to cause a significant change in emission rates.

Volatile organic emission samples were collected using VOST, while semivolatile organic emission samples were collected using MM5. GC and GC/MS was used to resolve and identify organic constituents from the various samples. It is nearly impossible to assess the quality of the emissions data from these pilot-scale studies because a list of "target compounds" were not reported. The following paragraphs will demonstrate that the level of emissions from these studies were generally much lower than from the full-scale tests. There is insufficient information to determine if this is due to differences in combustion conditions, air pollution control system efficiencies, or sampling and analysis of the effluent.

Tables 3.20 and 3.21 present a summary of the average relative magnitudes of total organic PICs versus CLPICs when normalized to input POHC and input chlorinated POHC concentrations, respectively. Data obtained at the exit of the afterburner (cf. Table 3.20) and the stack (cf. Table 3.21) indicate that %PIC emissions were always less than 0.01%, although the available database is sparse. Similar data indicates that %CLPIC emissions were greater than 0.01% in only ~20% of the tests. Close examination of the relative magnitudes of PIC and CLPIC emissions at the afterburner exit versus the stack indicates considerable scatter in the data. In general,

TABLE 3.19

EFFECT OF TEMPERATURE AND OXYGEN CONCENTRATION ON PIC EMISSIONS – 5-COMPONENT SYNTHETIC MIXTURE STUDY

Temperature[1] (°C)	$[O_2]$[1] (%, dry basis)	PIC Emissions[2] (μg/dscm)
1030	2.3	791.9
1114	3.3	55.2
943	5.6	775.1
1274	1.3	8.7
1091	5.1	878.2
945	8.2	191.9
1310	4.5	34.8
1077	9.2	431.5
1175	8.0	92.6
1105	4.7	141.9

[1] Measured at primary combustor exit.

[2] Measured at secondary combustor exit; measurements at primary combustor exit were not reported.

TABLE 3.20

% PIC EMISSIONS--- PILOT-SCALE AFTERBURNER SAMPLING

	ClBz Study [1]	PCB Study		4-Component Synthetic Mixture Study	
	%CLPIC Emissions (per CLPOHC Input)	%PIC Emissions (per POHC Input)	%CLPIC Emissions (per CLPOHC Input)	%PIC Emissions (per POHC Input)	%CLPIC Emissions (per CLPOHC Input)
Run 1	NA	8.50E-04	6.41E-04	1.21E-03	2.29E-02
Run 2	NA	NA	NA	1.95E-04	1.45E-03
Run 3	NA	7.02E-04	6.50E-04	3.36E-03	2.07E-02
Run 4	NA	NA	NA	3.22E-04	2.13E-04
Run 5	NA	NA	NA	2.00E-03	2.24E-02
Run 6	NA	3.58E-04	2.58E-04	2.57E-04	5.27E-03
Run 7	NA			4.86E-04	9.58E-04
Run 8	NA			2.92E-04	1.21E-02
Run 9	NA			1.33E-03	2.36E-03
Run 10	NA			2.61E-04	3.96E-03
Run 11	NA				
Run 12	2.03E-03				
Run 13	1.84E-03				
Run 14	1.53E-05				
Run 15	2.81E-01				
Run 16	2.82E-01				
Run 17	7.83E-03				
Run 18	NA				
Run 19	NA				
Run 20	1.46E-03				
Run 21	NA				
Run 22	NA				

Footnote:

1. Only ClPOHCs were present in the waste feed.

TABLE 3.21
% PIC EMISSIONS--PILOT-SCALE STACK SAMPLING

	ClBz Study [1]	PCB Study		4-Component Synthetic Mixture Study	
	%CLPIC Emissions (per CLPOHC Input)	%PIC Emissions (per POHC Input)	%CLPIC Emissions (per CLPOHC Input)	%PIC Emissions (per POHC Input)	%CLPIC Emissions (per CLPOHC Input)
Run 1	6.71E-03	8.03E-04	7.97E-04	2.37E-03	8.26E-03
Run 2	1.18E-02	NA	NA	3.33E-04	1.10E-03
Run 3	1.06E-02	1.43E-03	5.26E-04	6.95E-04	1.93E-03
Run 4	1.25E-02	NA	NA	NA	NA
Run 5	9.25E-03	NA	NA	NA	NA
Run 6	9.04E-03	1.63E-04	1.04E-04	NA	NA
Run 7	NA			NA	NA
Run 8	NA			NA	NA
Run 9	NA			NA	NA
Run 10	6.76E-03			NA	NA
Run 11	9.01E-03			NA	NA
Run 12	2.41E-03				
Run 13	1.70E-03				
Run 14	1.27E-03				
Run 15	1.66E-03				
Run 16	NA				
Run 17	NA				

Footnote:

1. Only ClPOHCs were present in the waste feed.

PIC and CLPIC emission rates were slightly greater at the afterburner exit, with CLPICs showing the greatest deviation between sampling points.

Tables 3.22 and 3.23 present specific PIC emissions data calculated from the raw data available from the three pilot-scale studies. For each compound, its frequency of occurrence, arithmetic mean emission rate, and geometric mean emission rate are presented. In calculation of the arithmetic and geometric mean emission rates, only values greater than analytical detection limits were considered, i.e., detection limit values were not assigned a numerical value.

Inspection of the afterburner data (cf. Table 3.22) indicates that methylene chloride, chloroform, benzene, 1,4-dichlorobenzene, and 1,2,3,4-tetrachlorobenzene are the most prevalent PICs, emitted in at least 67% of the tests. Of these compounds, only methylene chloride exhibited a significant emission rate ($\geq$ 100 μg/min). The disparity in arithmetic and geometric mean emission rates for some of these compounds indicates the absence of a normal distribution of emission data. Considering the scatter in the data, the geometric mean emission rate is a more representative measure of the actual emission rate for these compounds. Further inspection of Table 3.22 indicates that benzyl chloride, chlorobenzene, methyl ethyl ketone, trichloroethene, 1,1-dichloroethene, chloromethane, dichlorobromomethane, and bromoform also exhibited emission rates comparable to or greater than the more frequently observed compounds.

With the exception of dichlorobromomethane and bromoform, the observed PICs are consistent with the combustion of the reported POHC feed compositions. Dichlorobromomethane and in particular, bromoform were observed as PICs from the thermal destruction of Aroclor 1260. A detailed analysis of the chemical composition of this PCB waste was not reported.[97] As a result, it is not possible to distinguish the relative importance of volatile compound stripping versus PIC formation from minor contaminants in the waste feed. Analysis of data generated from the 4-component synthetic waste mixture studies[99] indicated that volatile compound stripping did not produce significant yields of brominated halomethanes.

TABLE 3.22

SPECIFIC PIC EMISSIONS--PILOT-SCALE AFTERBURNER SAMPLING

Compound	Frequency of Occurrence [1]	Arithmetic Mean Emission Rate [2] (ug/min)	Geometric Mean Emission Rate [3] (ug/min)	Formation Mechanism
Methylene chloride	2 / 3	1653.4	1184.5	Radical-molecule
1,4-Dichlorobenzene	2 / 3	60.8	60.8	Radical-molecule
Benzene	2 / 3	61.4	48.7	Radical-molecule
Chloroform	2 / 3	37.7	37.4	Association
1,2,4-Trichlorobenzene	2 / 3	22.6	20.4	Radical-molecule
1,2,3,4-Tetrachlorobenzene	2 / 3	9.3	9.3	Radical-molecule
Chlorobenzene	1 / 2	180.0	180.0	Radical-molecule
Pentachlorobenzene	1 / 2	16.1	16.1	Radical-molecule
Benzyl chloride	1 / 3	31636.8	31636.8	Association
Bromoform	1 / 3	3697.4	3697.4	Association
Chloromethane	1 / 3	2281.4	2281.4	Radical-molecule
Methyl ethyl ketone	1 / 3	230.6	230.6	Radical-molecule
Trichloroethene	1 / 3	173.8	173.8	Radical-molecule
Dichlorobromomethane	1 / 3	122.4	122.4	Association
1,1-Dichloroethene	1 / 3	114.8	114.8	Radical-molecule
trans-1,2-Dichloroethene	1 / 3	92.6	92.6	Radical-molecule
Pentachloroethane	1 / 3	70.3	70.3	Association
1,2,4,5-Tetrachlorobenzene	1 / 3	62.4	62.4	Radical-molecule
1,2-Dichlorobenzene	1 / 3	59.2	59.2	Radical-molecule
Hexachlorobenzene	1 / 3	54.9	54.9	Radical-molecule
2-Chloronaphthalene	1 / 3	17.7	17.7	Radical-molecule
alpha-Lindane	1 / 3	14.4	14.4	Analytical error
Carbon tetrachloride	1 / 3	10.5	10.5	Association
1,2,3-Trichlorobenzene	1 / 3	6.5	6.5	Radical-molecule
gamma-Lindane	1 / 3	4.8	4.8	Analytical error

Footnotes:

1. Defined as number of occurrences as PIC divided by total number of possible occurrences as PIC; denominator excludes presence in waste feed.
2. Arithmetic mean emission rate for all sites; individual data (per site) consist of an arithmetic mean based on the number of measurements obtained above detection limits.
3. Geometric mean emission rate for all sites; individual data (per site) consist of geometric mean based on the number of measurements obtained above detection limits.

TABLE 3.23
SPECIFIC PIC EMISSONS---PILOT-SCALE STACK SAMPLING

Compound	Frequency of Occurrence [1]	Arithmetic Mean Emission Rate [2] (ug/min)	Geometric Mean Emission Rate [3] (ug/min)	Formation Mechanism
Methylene chloride	2 / 3	1778.0	1695.0	Radical-molecule
Carbon tetrachloride	2 / 3	115.3	111.0	Association
Chloroform	2 / 3	86.0	75.1	Association
Benzene	2 / 3	64.4	63.6	Radical-molecule
1,2,3,4-Tetrachlorobenzene	2 / 3	38.5	38.5	Radical-molecule
1,2,4-Trichlorobenzene	2 / 3	73.7	26.9	Radical-molecule
Chlorobenzene	1 / 2	7.8	7.8	Radical-molecule
1,3-Dichlorobenzene	1 / 3	1027.2	1027.2	Radical-molecule
Benzyl chloride	1 / 3	729.2	953.5	Association
Hexachlorobenzene	1 / 3	354.8	354.8	Radical-molecule
Bromoform	1 / 3	334.2	334.2	Association
1,2-Dichlorobenzene	1 / 3	307.9	307.9	Radical-molecule
Trichloroethene	1 / 3	259.3	259.3	Radical-molecule
1,4-Dichlorobenzene	1 / 3	255.8	255.8	Radical-molecule
Dichlorobromomethane	1 / 3	243.7	243.7	Association
Hexachloroethane	1 / 3	227.7	227.7	Association
1,2,3,4-Tetrachloronaphthalene	1 / 3	189.9	189.9	Radical-molecule
1,2,4,5-Tetrachlorobenzene	1 / 3	107.3	107.3	Radical-molecule
alpha-Lindane	1 / 3	70.4	70.4	Analytical error
1,3-Dichloropropene	1 / 3	66.9	66.9	Radical-molecule
Chloromethane	1 / 3	59.7	59.7	Radical-molecule
1,2-Dichloropropane	1 / 3	59.1	59.1	Association
Methyl ethyl ketone	1 / 3	57.0	57.0	Radical-molecule
gamma-Lindane	1 / 3	51.1	51.1	Analytical error
1,3,5-Trichlorobenzene	1 / 3	44.1	44.1	Radical-molecule
1,1-Dichloroethene	1 / 3	33.6	33.6	Molec. Elim.
Pentachloroethane	1 / 3	29.9	29.9	Association
trans-1,2-Dichloroethene	1 / 3	13.2	13.2	Radical-molecule
1,3-Hexachlorobutadiene	1 / 3	11.3	11.3	Radical-molecule
1,2,3-Trichlorobenzene	1 / 3	0.4	0.4	Radical-molecule

Footnotes:

1. Defined as number of occurrences as PIC divided by total number of possible occurrences as PIC; denominator excludes presence in waste feed.
2. Arithmetic mean emission rate for all sites; individual data (per site) consist of an arithmetic mean based on the number of measurements obtained above detection limits.
3. Geometric mean emission rate for all sites; individual data (per site) consist of geometric mean based on the number of measurements obtained above detection limits.

For the types of PICs observed, emission mechanisms are divided into two categories, radical-molecule and radical association reactions. The relative contributions of these two mechanisms depend on the relative importance of the following parameters: 1) frequency of occurrence, or 2) geometric mean emission rate. Considering the former as more significant suggests that 67% of the PICs are emitted by a radical-molecule mechanism. Furthermore, based on geometric mean emission rate ($\geq$ 100 μg/min), the data indicates that 71% of the PICs are emitted by a radical-molecule mechanism. The above analysis excludes the brominated halomethane compounds because their mechanism of formation may be related to stripping of scrubber makeup water.

Inspection of the stack data (cf. Table 3.23) indicates that methylene chloride, chloroform, carbon tetrachloride, benzene, 1,2,4-trichlorobenzene, and 1,2,3,4-tetrachlorbenzene are the most prevalent PICs, emitted in at least 67% of all possible cases. Of these compounds only methylene chloride exhibited a significant emission rate ($\geq$ 100 μg/min). Further inspection of Table 3.23 indicates that carbon tetrachloride, 1,3-dichlorobenzene, benzyl chloride, hexachlorobenzene, bromoform, 1,2-dichlorobenzene, trichloroethene, 1,4-dichlorobenzene, dichlorobromomethane, hexachloroethane, 1,2,3,4-tetrachloronaphthalene, and 1,2,3,4-tetrachlorobenzene also exhibited emission rates comparable to or greater than the more frequently observed compounds.

Emission mechanisms for the specific PICs identified are also listed in Table 3.23. If we follow the same procedure invoked previously, considering PIC frequency of occurrence as the classification parameter indicates that 67% of PICs were emitted by radical-molecule mechanisms. Furthermore, based on geometric mean emission rate ($\geq$ 100 μg/min), the data also indicates that 73% of the PICs are emitted by radical-molecule mechanisms. The above analysis once again excludes the brominated halomethane compounds because their mechanism of formation may be due to stripping of scrubber makeup water.

Two independent pilot-scale research programs have also been conducted to better understand the effect of different failure-induced conditions on

POHC destruction and "transient puff" or PIC formation. These failure-induced conditions include poor atomization (for liquid wastes), overcharging (due to batch feeding of drummed solid or liquid wastes), poor waste/air mixing, and thermal quenching due to cold boundary layers near combustor walls.

Kramlich et al.[106] conducted flame-mode thermal destruction studies aimed at determining flame perturbation conditions resulting in incomplete waste destruction. Two independent series of tests were conducted utilizing a microspray reactor simulating single waste droplet combustion in a laminar flame environment, and a turbulent flame reactor where auxiliary fuel doped with waste was injected into a swirl-stabilized turbulent spray flame. Thermal destruction behavior of equimolar mixtures of acrylonitrile, benzene, chlorobenzene and chloroform were analyzed.

Results indicated that the flame failed to completely destroy wastes only when operating parameters were significantly perturbed from their high efficiency values. Failure conditions were identified which were associated with high and low excess air, poor fuel/waste atomization and flame impingement on cold surfaces. Variations in burner air velocity and waste concentration did not induce failure. Effects of fuel type were not studied. In the turbulent flow reactor studies, combustion intermediate measurements (CO and TUHC) correlated with waste DE over % theoretical air ranging from ~130 to ~200%. Important relationships between waste intermediate concentrations, i.e., PICs, and combustion intermediate measurements, under optimal and failure-induced conditions, were not studied.

It has been hypothesized that batch introduction of waste-filled drums or containers into rotary kiln incinerators can also lead to transient PIC overcharging conditions, which have been denoted as "puffs". In a series of studies designed to gain engineering insight into this very complex problem, Linak et al[107,108] have reported the results of an experimental study utilizing a 73 kW (250,000 Btu/hr) pilot-scale rotary kiln incinerator simulator. Surrogate solid wastes in the form of plastic rods and surrogate liquid wastes on corncob sorbent in cardboard containers were investigated.

Parametric studies were used to determine the extent to which waste and kiln variables, i.e., charge mass, charge surface area, charge composition, kiln temperature, and kiln rotation speed, affected the intensity (peak FID emission) and magnitude (time-integrated FID emission) of puffs.

Results demonstrated the relative ease with which failure conditions could be achieved, even under high kiln temperature and high excess air values. Limited chemical analyses indicated that puffs arising from even innocuous surrogate wastes can contain numerous toxic PICs even though >99.99% POHC DRE was achieved. For several liquid waste experiments, increasing kiln temperature and rotation adversely affected puff intensity due to increased devolatilization and liquid evaporation rates. Large effects of waste composition were evident, and for solid wastes, waste surface area was a critical variable.

A significant distinguishing property of both solid and liquid wastes, as related to puff generation, was the stoichiometric oxygen requirement. However, other physical mechanisms governing puff generation for solid wastes were different than those for liquid wastes. For solid wastes, volatile release rate depended on the rate of pyrolysis of the plastic, and this result was correlated with differential thermogravimetric analyses. For liquid wastes on sorbents, TGA analyses showed no distinguishing features between wastes, and therefore could not be related to puff generation. Instead, it was proposed that volatile release rate for liquid wastes are controlled by heat transfer to the sorbent, and surface exposure of the sorbent to the surroundings. If correct, it follows that important waste parameters for liquid wastes are normal boiling points and latent heats of vaporization.

Limited qualitative analysis of transient puffs were determined using VOST and SASS sampling trains, in conjunction with GC-MS analysis. Results indicated that chlorinated PIC compounds were more likely to form when mixtures of dissimilar materials, i.e., polyethylene (PE) and polyvinylchloride (PVC) or toluene and carbon tetrachloride, are burned, than when PVC or carbon tetrachloride are burned alone. The authors stated that these results are consistent with puff generation mechanisms because excess oxygen is neither totally depleted nor displaced due to the slow volatile heat release rates of these highly chlorinated compounds. Contrarily, excess oxygen is more extensively depleted or displaced by PE or toluene alone, and this is consistent with their formation of intense puffs of great magnitude. PE/PVC or toluene/carbon tetrachloride mixtures therefore provide both the necessary chlorine and pyrolytic conditions to produce chlorinated PICs.

The results of the puff chemical analysis appear to demonstrate the importance of volatile release rates. However, firmer conclusions will result from a more thorough chemical analysis of the puffs generated.

Summary

Analysis of specific PIC emissions from pilot- and full-scale emission sources in relation to their predicted stability and mechanisms of formation has produced three major observations. The first observation is related to the relative magnitude of PICs observed. The emissions analysis resulted in the following relationship between total PIC emission rates and emission source:

Boilers > Kilns ≅ Incinerators >> Pilot-scale

Explanations for the differences in emission rates must include potential variations in the following site-specific "physical" kinetic factors: 1) microscale mixing of waste and oxidant, 2) rates of liquid waste vaporization and solid waste sublimation, vaporization, and pyrolysis, and 3) the existence of thermal quenching regions within the flame and post-flame zones.

In addition to these "physical" kinetic parameters, the completeness of site-specific sampling and analysis procedures may also play an important role in determining the magnitude of emission rates observed in full-scale systems. Evidence for this hypothesis was demonstrated from a correlation between completeness of chemical analysis procedures for PIC characterization and the magnitude of total PIC emissions. The most dramatic example of this correlation involved the recent Dow incinerator study, where nearly 70% of the trace organic emissions (including CH_4) were recovered. Total PIC emissions from this study were approximately 1-3 orders of magnitude greater than the other full-scale incinerators tested. Although mass balances of organics from the other full-scale incinerator studies reviewed in this report cannot be ascertained, it is unlikely that closures of >50% (including CH_4) were obtained.

With regard to differences in boiler versus incinerator emissions, the emissions analysis indicated that emissions from fuel combustion were not primarily responsible for the increased boiler emissions, as had been previously proposed. The limited data suggested that other factors including fuel/waste physical and chemical interactions and completeness of sampling and analysis methods were important.

The most surprising result of the comparison of emission rates versus emission source was the much lower emission rates of pilot-scale versus full-scale systems. Differences on the order of one to two orders of magnitude were evident. Additional cause for this disparity beyond the already delineated site-specific factors is unclear.

The second major observation is concerned with the types of PICs observed. To the degree that total organic PICs were measured, the most prevalent class of PICs emitted were the chlorinated methanes. Benzene, toluene, and naphthalene represented the most prevalent aromatic species observed. PICs of secondary prevalence, yet still observed in at least 50% of possible cases, included the chlorinated ethenes and the chlorinated ethanes. The general absence of the chlorinated ethenes and aromatic species such as toluene, styrene, naphthalene and other semivolatiles from the pilot-scale data must be considered as a surprising, if not questionable result. Halomethanes consisting of brominated chloromethanes were prevalent in the incinerator effluent. Their general absence in the analysis of the boiler and kiln data casts doubt over their true mechanism of formation in incinerator systems. Analysis of the scrubber makeup water in the TWI incinerator study indicated that stripping of brominated chloromethanes represented a significant fraction of the emission of these compounds.[17]

Other full-scale and pilot-scale studies, however, have indicated that the degree of volatile compound stripping is generally insignificant.[16,66,99] The ambiguous nature of these results suggest that this phenomena is a dynamic process and must be determined on a site-specific basis.

The third major observation from the analysis of the specific PIC emissions is related to their mechanism of formation. The data from all three types of thermal disposal facilities indicate that radical-molecule reactions and radical association reactions are by far the dominant emission mechanisms. This conclusion is reached independent of the relative weighting of PIC classification parameters, e.g., PIC prevalence versus geometric mean emission rate. Analysis of specific PICs generated by these two emission mechanisms indicated that radical association reactions varied in significance from ~30% to as high as 50%, depending on the emission source. The level of significance of this surprising emission mechanism was highest for the full-scale incinerators.

As discussed in Section 2, radical-molecule and radical-radical association reactions are the dominant chemical reactions occurring in the post-flame and cool zones of incineration systems. Although the available PIC emissions database is very limited, the mechanistic implications of this analysis suggest that the cooler regions downstream of the flame zone may be responsible for a significant fraction of the observed emissions. The degree to which these types of reactions contribute to the observed emissions is dependent on several facility-dependent factors, the most important perhaps being post-flame zone waste/air mixing and cool zone quenching rates.

SECTION 4

DISCUSSION

In Section 2, a general theory concerning the mechanisms of PIC formation in full-scale thermal disposal systems was presented. In Section 3, organic emissions from pilot-and full-scale testing of hazardous waste incinerators, co-fired boilers, and co-fired kilns were quantified, and major PIC formation zones and mechanisms were delineated. If the laws of chemistry and physics are not violated in the process of thermal destruction of toxic wastes, there should be a relationship between various operation and design parameters and PIC emissions. In order to discern which of these parameters most significantly affect PIC emissions and how they relate to the PIC formation zones and mechanisms delineated in Section 3, we have conducted a statistical analysis of the field test results.

Table 4.1 presents a list of quantities that may be used to characterize the emissions of PICs from the facilities that were included in this study. These quantities were used as dependent variables in the statistical analysis scheme. Table 4.2 presents a list of design and operation parameters that were used as independent variables. Also included in Table 4.2 is a list of comments concerning the a priori manner in which these parameters were expected to affect PIC emissions. The dependent and independent variables were applied to each source as appropriate. For example, correlations were only attempted for the PICs listed as dependent variables if measurements were made for that PIC at a given source. It should also be noted that values for many of the dependent and independent variables were not available or calculable from the data presented in the field test reports. This was a major limitation of the study.

There exists a number of different statistical methods for the determination of the relationship between two or more variables. These methods are normally used to determine exactly what the relationship is, usually

TABLE 4.1

Quantities Characteristic of PIC Emissions Used as Dependent Variables in the Statistical Analysis

Variable	Abbreviation
Total PIC Emission Rate (ug/min)	TOT PIC EMISS RATE (ug/min)
Total PIC Emission Concentration (ug/dscm)	TOT PIC EMISS CONC (ug/dscm)
Total PIC Emission Concentration (10% O2)	TOT PIC EMISS CONC (10% O2)
% PIC Emission/POHC Input	% PIC EMISS/POHC INPUT
% PIC Emission/Waste Input	% PIC EMISS/WASTE INPUT
Total Chlorinated PIC Emission Rate (ug/min)	TOT ClPIC EMISS RATE (ug/min)
Total Chlorinated PIC Emission Concentration (ug/dscm)	TOT ClPIC EMISS CONC (ug/dscm)
Total Chlorinated PIC Emission Concentration (10% O2)	TOT ClPIC EMISS CONC (10% O2)
% Chlorinated PIC Emission/POHC Input	% ClPIC EMISS/POHC INPUT
% Chlorinated PIC Emission/Waste Input	% ClPIC EMISS/WASTE INPUT
PIC:POHC Ratio	PIC:POHC RATIO
Benzene Emission Rate (ug/min)	BZ EMISS RATE (ug/min)
Benzene Emission Concentration (ug/dscm)	BZ EMISS CONC (ug/dscm)
Benzene Emission Concentration (10% O2)	BZ EMISS CONC (10% O2)
% Benzene Emission/POHC Input	% BZ EMISS/POHC INPUT
% Benzene Emission/Waste Input	% BZ EMISS/WASTE INPUT
Toluene Emission Rate (ug/min)	TOL EMISS RATE (ug/min)
Toluene Emission Concentration (ug/dscm)	TOL EMISS CONC (ug/dscm)
Toluene Emission Concentration (10% O2)	TOL EMISS CONC (10% O2)
% Toluene Emission/POHC Input	% TOL EMISS/POHC INPUT
% Toluene Emission/Waste Input	% TOL EMISS/WASTE INPUT
Chloroform Emission Rate (ug/min)	CHCl3 EMISS RATE (ug/min)
Chloroform Emission Concentration (ug/dscm)	CHCl3 EMISS CONC (ug/dscm)
Chloroform Emission Concentration (10% O2)	CHCl3 EMISS CONC (10% O2)
% Chloroform Emission/POHC Input	% CHCl3 EMISS/POHC INPUT
% Chloroform Emission/Waste Input	% CHCl3 EMISS/WASTE
Chloromethane Emission Rate (ug/min)	CH3Cl EMISS RATE (ug/min)
Chloromethane Emission Concentration (ug/dscm)	CH3Cl EMISS CONC (ug/dscm)
Chloromethane Emission Concentration (10% O2)	CH3Cl EMISS CONC (10% O2)
% Chloromethane Emission/POHC Input	% CH3Cl EMISS/POHC INPUT
% Chloromethane Emission/Waste Input	% CH3Cl EMISS/WASTE INPUT
Dichloromethane Emission Rate (ug/min)	CH2Cl2 EMISS RATE (ug/min)
Dichloromethane Emission Concentration (ug/dscm)	CH2Cl2 EMISS CONC (ug/dscm)
Dichloromethane Emission Concentration (10% O2)	CH2Cl2 EMISS CONC (10% O2)
% Dichloromethane Emission/POHC Input	% CH2Cl2 EMISS/POHC INPUT
% Dichloromethane Emission/Waste Input	% CH2Cl2 EMISS/WASTE INPUT
1,3-Dichlorobenzene Emission Rate (ug/min)	1,3-DICLBZ EMISS RATE (ug/min)
1,3-Dichlorobenzene Emission Concentration (ug/dscm)	1,3-DICLBZ EMISS CONC (ug/dscm)
1,3-Dichlorobenzene Emission Concentration (10% O2)	1,3-DICLBZ EMISS CONC (10% O2)
% 1,3-Dichlorobenzene Emission/POHC Input	% 1,3-DICLBZ EMISS/POHC INPUT
% 1,3-Dichlorobenzene Emission/Waste Input	% 1,3-DICLBZ EMISS/WASTE INPUT
Chlorobenzene Emission Rate (ug/min)	CLBZ EMISS RATE (ug/min)
Chlorobenzene Emission Concentration (ug/dscm)	CLBZ EMISS CONC (ug/dscm)
Chlorobenzene Emission Concentration (10% O2)	CLBZ EMISS CONC (10% O2)
% Chlorobenzene Emission/POHC Input	% CLBZ EMISS/POHC INPUT
% Chlorobenzene Emission/Waste Input	% CLBZ EMISS/WASTE INPUT
Trichloroethene Emission Rate (ug/min)	TCE EMISS RATE (ug/min)
Trichloroethene Emission Concentration (ug/dscm)	TCE EMISS CONC (ug/dscm)
Trichloroethene Emission Concentration (10% O2)	TCE EMISS CONC (10% O2)
% Trichloroethene Emission/POHC Input	% TCE EMISS/POHC INPUT
% Trichloroethene Emission/Waste Input	% TCE EMISS/WASTE INPUT
Pentachloroethane Emission Rate (ug/min)	PCA EMISS RATE (ug/min)
Pentachloroethane Emission Concentration (ug/dscm)	PCA EMISS CONC (ug/dscm)
Pentachloroethane Emission Concentration (10% O2)	PCA EMISS CONC (10% O2)
% Pentachloroethane Emission/POHC Input	% PCA EMISS/POHC INPUT
% Pentachloroethane Emission/Waste Input	% PCA EMISS/WASTE INPUT
1,1,1-Trichloroethane Emission Rate (ug/min)	TCA EMISS RATE (ug/min)
1,1,1-Trichloroethane Emission Concentration (ug/dscm)	TCA EMISS CONC (ug/dscm)
1,1,1-Trichloroethane Emission Concentration (10% O2)	TCA EMISS CONC (10% O2)
% 1,1,1-Trichloroethane Emission/POHC Input	% TCA EMISS/POHC INPUT
% 1,1,1-Trichloroethane Emission/Waste Input	% TCA EMISS/WASTE INPUT
1,1-Dichloroethene Emission Rate (ug/min)	1,1-DCE EMISS RATE (ug/min)
1,1-Dichloroethene Emission Concentration (ug/dscm)	1,1-DCE EMISS CONC (ug/dscm)
1,1-Dichloroethene Emission Concentration (10% O2)	1,1-DCE EMISS CONC (10% O2)
% 1,1-Dichloroethene Emission/POHC Input	% 1,1-DCE EMISS/POHC INPUT
% 1,1-Dichloroethene Emission/Waste Input	% 1,1-DCE EMISS/WASTE INPUT
Vinyl Chloride Emission Rate (ug/min)	VC EMISS RATE (ug/min)
Vinyl Chloride Emission Concentration (ug/dscm)	VC EMISS CONC (ug/dscm)
Vinyl Chloride Emission Concentration (10% O2)	VC EMISS CONC (10% O2)
% Vinyl Chloride Emission/POHC Input	% VC EMISS/POHC INPUT
% Vinyl Chloride Emission/Waste Input	% VC EMISS/WASTE INPUT

TABLE 4.2

Quantities Characteristic of PIC Emissions Used as Independent Variables in the Statistical Analysis

Variable	Abbreviation	Description
Temperature Primary (°C)	TEMP PRIM(°C)	Decomposition Temperature in the Primary Chamber
Temperature Secondary (°C)	TEMP SEC(°C)	Decomposition Temperature in the Secondary Chamber
Temperature Quench (°C)	TEMP QNCH(°C)	Decomposition Temperature in the Quenching Chamber
Temperature APCD (°C)	TEMP APCD(°C)	Surface/recombination reactions
Temperature Stack (°C)	TEMP STK(°C)	Surface/recombination reactions
Temperature Afterburner (°C)	TEMP AB(°C)	Decomposition Temperature in the Afterburner
Temperature Kiln (°C)	TEMP KILN(°C)	Decomposition Temperature in the Kiln
Temperature Furnace (°C)	TEMP FURN(°C)	Decomposition Temperature in the Furnace
Temperature Boiler (°C)	TEMP BOIL(°C)	Decomposition Temperature in the Boiler
Temperature Economizer (°C)	TEMP ECON(°C)	Decomposition Temperature in the Economizer
Residence Time Furnace (s)	RT FURN(s)	Time at Temperature in the Furnace
Residence Time Secondary (s)	RT SEC(s)	Time at Temperature in the Secondary Chamber
Residence Time Afterburner (s)	RT AB(s)	Time at Temperature in the Afterburner
Residence Time Total (s)	RT TOTAL(s)	Overall Time at Temperature
Flow Secondary (dscmm)	FLOW SEC(dscmm)	Surface/recombination rxns
Flow Stack (dscmm)	FLOW STK(dscmm)	Surface/recombination rxns
Flow Afterburner (dscmm)	FLOW AB(dscmm)	Surface/recombination rxns
Flow Kiln (dscmm)	FLOW KILN(dscmm)	Surface/recombination rxns
Oxygen Primary (%)	O_2 PRIM(%)	Mixing in the Primary Chamber
Oxygen Secondary (%)	O_2 SEC(%)	Mixing in the Secondary Chamber
Oxygen Stack (dry,%)	O_2 STK(dry,%)	Oxidation in cool zones
Oxygen Afterburner (%)	O_2 AB(%)	Mixing in the Afterburner
Oxygen Kiln (%)	O_2 KILN(%)	Mixing in the Kiln
Oxygen Boiler (%)	O_2 BOILER(%)	Mixing in the Boiler
Carbon Monoxide Primary (ppm)	CO PRIM(ppm)	Efficiency Surrogate
Carbon Monoxide Stack (ppm)	CO STK(ppm)	Efficiency Surrogate
Carbon Monoxide Kiln (ppm)	CO KILN(ppm)	Efficiency Surrogate
NOx Primary (ppm)	NOx PRIM(ppm)	Temperature History Surrogate
TUHC Cold (ppm, 3% O_2)	TUHC COLD(ppm,3%O_2)	Total Organic Surrogate
TUHC Hot (ppm, 3% O_2)	TUHC HOT(ppm,3%O_2)	Total Organic Surrogate, heated line
Particulate Stack (g/sec)	PART STK(g/sec)	Sorption/Surface Reactions
Particulate Stack (mg/dscm)	PART STK(mg/dscm)	Sorption/Surface Reactions
Particulate APCD (g/dscm)	PART APCD(g/dscm)	Sorption/Surface Reactions
APCD Efficiency (%)	APCD EFFIC (%)	Sorption
Chlorine POHC Feed (g/min)	ClPOHC FEED(g/min)	Chlorination Reactions/Flame Stability
HCl Stack (mg/dscm)	HCl STK(mg/dscm)	Chlorination Reactions/Flame Stability
Chlorine Scrubber In	Cl SCRUBB IN (mg/L)	PICs Stripped from Scrubber
Chlorine Scrubber Out	Cl SCRUBB OUT (mg/L)	PICs Stripped from Scrubber
Chlorine Out-vs-Chlorine In	Cl OUT-vs-Cl IN	PICs Stripped from Scrubber
Load	LOAD(MBtu/hr)	Stress to the facility
Load	LOAD(lb/hr)	Stress to the facility
Waste-vs-Fuel Ratio	WASTE-vs-FUEL ratio	Stress to the facility
# POHCs	# POHCS	#s and types of PICs
C_1 to C_6 Hydrocarbons	C_1 TO C_6 HC	Substitute for TUHC monitor

involving either linear or non-linear mathematical expressions. For example, to determine if a group of data has a linear relationship, one may use the method of least squares and determine the slope and intercept for the data, comparing residuals to ascertain the degree of the linear association. In some cases, the mathematical relationship between data can be determined after one has established that a relationship *exists* between the data; i.e., the data are *not* independent. It is useful to determine (at least on a preliminary basis) whether there is the *existence* of an association between variables and what the degree of strength of that association is. Methods such as this can be an excellent screening tool for eventually determining mathematical relationships for modeling complex processes.

The Spearman rank order correlation coefficient is one method for determining the degree of the existence of a relationship between two sets of ranked data. By ranking paired data (lowest to highest) and assigning ranks to each data value, the Spearman coefficient can be determined very simply. The equation:

$$R = 1 - \frac{6 * \sum_{i=0}^{n} D_i^2}{n * (n^2 - 1)} \qquad (4.1)$$

where D_i = difference between ranked data pairs
n = number of data pairs

produces a R value between -1 and 1 which describes the degree of the relationship between two variables. A positive value for R close to 1 denotes a strong positive, direct relationship between two variables where a -1 denotes a strong negative, inverse relationship between paired data. The R values can be related to confidence intervals to describe the confidence associated with stating that two variables are or are not associated.

The results of this analysis for each facility for which there were 4 more data points for each correlation are presented in Tables 4.3-4.12. Only the parameters for which there were enough data to conduct a statistically significant analysis were included in the table for each facility. A blank entry indicates there was no statistically significant correlation.

Table 4.3

Statistical Analysis of PIC Data from the Dow Hazardous Waste Incinerator

CONFIDENCE INTERVALS (CI):

'OO' = >or= 99% (inverse relation)
'O' = 90 - 95% (inverse relation)
'++' = >or= 95% (direct relation)
'+' = 90 - 95% (direct relation)
blank = no significant relation
NA = not changed

	TEMP PRIM °C	TEMP SEC °C	TEMP APCD °C	TEMP STK °C	FLOW STK [illegible]	O2 STK %	CO STK [illegible]	TUHC COLD [illegible]	TUHC HOT [illegible]	PART STF [illegible]	PART APCD [illegible]	APCD EFFIC %	OPOHC FEED [illegible]	HCl STK [illegible]	Cl SCRBS IN mg/L	Cl SCRBS OUT mg/L	Cl OUT → Cl IN SCRUS ratio	LOAD MBtu/hr	LOAD lb/hr	WASTE → FUEL ratio	BZ EMISS RATE ug/min	BZ EMISS CONC ug/dscm	BZ EMISS CONC 10% O2	% BZ EMISS /POHC by	% BZ EMISS WASTE by	TOL EMISS RATE ug/min	TOL EMISS CONC ug/dscm	TOL EMISS CONC 10% O2	% TOL EMISS /POHC by	% TOL EMISS WASTE by	BZ+TOL EMISS RATE ug/min	BZ+TOL EMISS CONC ug/dscm	BZ+TOL EMISS CONC 10% O2	% BZ+TOL EMISS /POHC by	% BZ+TOL EMISS WASTE by
TOT PC EMISS RATE (ug/min)																																			
TOT PC EMISS CONC (ug/dscm)																																			
TOT PC EMISS CONC (10% O2)																						++	++												
% PC EMISS/ POHC INPUT		+																							+					+	+	+		+	+
% PC EMISS/WASTE INPUT		+																				+	+		+					+	++	++	+	++	+
TOT OPC EMISS RATE (ug/min)																																			
TOT OPC EMISS CONC (ug/dscm)																																			
TOT OPC EMISS CONC (10% O2)																						++	++												
% OPC EMISS/ OPOHC INPUT	+	+																																	
% OPC EMISS/ OWASTE INPUT		++																																	
PIC : POHC RATIO		++																																	
BZ EMISS RATE (ug/min)																			+	O	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BZ EMISS CONC (ug/dscm)																					NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BZ EMISS CONC (10% O2)																					NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
% BZ EMISS/ POHC INPUT																			+		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
% BZ EMISS/WASTE INPUT														+					+		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CHCl3 EMISS RATE (ug/min)						OO				+	+							++																	
CHCl3 EMISS CONC (ug/dscm)						O												+																	
CHCl3 EMISS CONC (10% O2)																		+																	
% CHCl3 EMISS/ POHC INPUT			+	+		O				++	++							+																	
% CHCl3 EMISS/WASTE INPUT			+	+						+	+							+																	
TOL EMISS RATE (ug/min)																	++				NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
TOL EMISS CONC (ug/dscm)																	++				NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
TOL EMISS CONC (10% O2)																	++				NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
% TOL EMISS/ POHC INPUT			++	++		O				++	++	+			O						NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
% TOL EMISS/ WASTE INPUT															+						NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table 4.4

Statistical Analysis of PIC Data from the American Cyanamid Hazardous Waste Incinerator

CONFIDENCE INTERVALS (CI):

"--" = >/= 95% (inverse relation)

"-" = 90 - 95% (inverse relation)

"++" = >/= 95% (direct relation)

"+" = 90 - 95% (direct relation)

blank = no significant relation

NA = not attempted

	TEMP STK	RT TOT	FLOW STK	O_2 STK	PART STK	PART APCD	GPONG FEED	NO STK	LOAD	LOAD	BZ EMISS RATE	BZ EMISS CONC	BZ EMISS CONC	% BZ EMISS	% BZ EMISS	TOL EMISS RATE	TOL EMISS CONC	TOL EMISS CONC	% TOL EMISS	% TOL EMISS	BZ+TOL EMISS RATE	BZ+TOL EMISS CONC	BZ+TOL EMISS CONC	% BZ-TOL EMISS	% BZ-TOL EMISS
	°C	s	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	ug/min	ug/dscm	10% O_2	POHC Inp.	WASTE Inp.	ug/min	ug/dscm	10% O_2	POHC Inp.	WASTE Inp.	ug/min	ug/dscm	10% O_2	POHC Inp.	WASTE Inp.
TOT PIC EMISS RATE (ug/min)			[illegible]						[illegible]																
TOT PIC EMISS CONC (ug/dscm)			[illegible]						[illegible]																
TOT PIC EMISS CONC (10% O_2)			[illegible]						[illegible]																
% PIC EMISS / POHC INPUT																[illegible]									
% PIC EMISS / WASTE INPUT			[illegible]																						
TOT CPIC EMISS RATE (ug/min)				[illegible]								[illegible]	[illegible]		[illegible]										
TOT CPIC EMISS CONC (ug/dscm)				[illegible]								[illegible]	[illegible]		[illegible]										
TOT CPIC EMISS CONC (10% O_2)				[illegible]								[illegible]	[illegible]		[illegible]										
% CPIC EMISS / CPOHC INPUT				[illegible]								[illegible]	[illegible]		[illegible]										
% CPIC EMISS / CWASTE INPUT				[illegible]								[illegible]	[illegible]		[illegible]										
PIC : POHC RATIO											[illegible]			[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
$CHCl_3$ EMISS RATE (ug/min)																									
$CHCl_3$ EMISS CONC (ug/dscm)																									
$CHCl_3$ EMISS CON (10% O_2)																									
% $CHCl_3$ EMISS / POHC INPUT																									
% $CHCl_3$ EMISS / WASTE INPUT																									
BZ EMISS RATE (ug/min)											[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
BZ EMISS CONC (ug/dscm)				[illegible]							[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
BZ EMISS CON (10% O_2)				[illegible]							[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
% BZ EMISS / POHC INPUT											[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
% BZ EMISS / WASTE INPUT				[illegible]							[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TOL EMISS RATE (ug/min)											[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TOL EMISS CONC (ug/dscm)											[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TOL EMISS CON (10% O_2)											[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
% TOL EMISS / POHC INPUT											[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
% TOL EMISS / WASTE INPUT											[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TCE EMISS RATE (ug/min)																									
TCE EMISS CONC (ug/dscm)																									
TCE EMISS CON (10% O_2)																									
% TCE EMISS / POHC INPUT																									
% TCE EMISS / WASTE INPUT																									

Table 4.5

Statistical Analysis of PIC Data from the [illegible] Hazardous Waste Incinerator

CONFIDENCE INTERVALS (CI):

'VV' = > or = 90% (inverse relation)
'V' = 80 - 90% (inverse relation)
'++' = > or = 90% (direct relation)
'+' = 80 - 90% (direct relation)
blank = no significant relation
NS = not sampled

	TEMP PRIM °C	TEMP SEC °C	TEMP STK °C	RT SEC s	FLOW STK dscfm	O2 STK dry %	CO STK ppm	TURB COLD [illegible]	PART STK [illegible]	PART APCD [illegible]	POHC FEED [illegible]	HCl STK [illegible]	LOAD [illegible]	LOAD [illegible]	BZ EMISS RATE ug/min	BZ EMISS CONC ug/dscm	BZ EMISS CONC 10% O2	% BZ EMISS POHC kg	% BZ EMISS WASTE kg	TOL EMISS RATE ug/min	TOL EMISS CONC ug/dscm	TOL EMISS CONC 10% O2	% TOL EMISS POHC kg	% TOL EMISS WASTE kg	BZ+TOL EMISS RATE ug/min	BZ+TOL EMISS CONC ug/dscm	BZ+TOL EMISS CONC 10% O2	% BZ+TOL EMISS POHC kg	% BZ+TOL EMISS WASTE kg
TOT PIC EMISS RATE (ug/min)															++	++	++	++	++								++	++	++
TOT PIC EMISS CONC (ug/dscm)															++	++	++	++	++								++	++	++
TOT PIC EMISS CONC (10% O2)															++	++	++	++	++								++	++	++
% PIC EMISS / POHC INPUT																						++		++	++	++			
% PIC EMISS / WASTE INPUT															++	++	++	++	++								++	++	++
TOT CIPIC EMISS RATE (ug/min)				++		++		+																					
TOT CIPIC EMISS CONC (ug/dscm)				++		++		+																					
TOT CIPIC EMISS CONC (10% O2)				++		++		+																					
% CIPIC EMISS / CIPOHC INPUT															++	++	++	++	++								++	++	++
% CIPIC EMISS / CIWASTE INPUT				++		++		+																					
PIC : POHC RATIO																				++	++								
CHCL3 EMISS RATE (ug/min)																													
CHCL3 EMISS CONC (ug/dscm)																													
CHCL3 EMISS CONC (10% O2)			VV																										
% CHCL3 EMISS / POHC INPUT																													
% CHCL3 EMISS / WASTE INPUT																													
BZ EMISS RATE (ug/min)															NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
BZ EMISS CONC (ug/dscm)															NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
BZ EMISS CONC (10% O2)															NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
% BZ EMISS / POHC INPUT															NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
% BZ EMISS / WASTE INPUT															NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
1,1,1-TCA EMISS RATE (ug/min)																													
1,1,1-TCA EMISS CONC (ug/dscm)	VV																												
1,1,1-TCA EMISS CONC (10% O2)	VV																												
% 1,1,1-TCA EMISS / POHC INPUT																													
% 1,1,1-TCA EMISS / WASTE INPUT																													
TOL EMISS RATE (ug/min)															NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
TOL EMISS CONC (ug/dscm)															NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
TOL EMISS CONC (10% O2)															NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
% TOL EMISS / POHC INPUT															NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
% TOL EMISS / WASTE INPUT															NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

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Table 4.6

Statistical Analysis of PIC Data from the TWI Hazardous Waste Incinerator under Optimal and Failure Mode Conditions

CONFIDENCE INTERVALS (CI):

'OO' = >or= 90% (inverse relation)
'O' = 80 - 90% (inverse relation)
'↔' = >or= 90% (direct relation)
'+' = 80 - 90% (direct relation)
blank = no significant relation
NA = not attempted

	TWI Optimal Operation																TWI Failure Mode Operation									
	TEMP PRIM °C	TEMP SEC °C	TEMP CNCH °C	TEMP STK °C	RT TOT s	FLOW STK dscfm	O2 STK dry,%	CO STK ppm	THC COLD ppm,7%O2	PART STK g/sec	PART APCD g/dscm	QPOHC FEED g/min	HCl STK mg/dscm	LOAD MBtu/hr	WASTE↔FUEL ratio	# POHCS	TEMP PRIM °C	TEMP SEC °C	TEMP QNCH °C	TEMP STK °C	RT TOT s	FLOW STK dscfm	O2 STK dry,%	CO STK ppm	QPOHC FEED g/min	LOAD MBtu/hr
TOT PIC EMISS RATE (ug/min)													↔					OO								
TOT PIC EMISS CONC (ug/dscm)													↔											OO		
TOT PIC EMISS CONC (10% O2)														↔										OO		
% PIC EMISS/ POHC INPUT														↔										OO		
% PIC EMISS/WASTE INPUT															OO									OO		
TOT CIPIC EMISS RATE (ug/min)															OO											
TOT CIPIC EMISS CONC (ug/dscm)															OO											
TOT CIPIC EMISS CON (10% O2)															OO											
% CIPIC EMISS/ CIPOHC INPUT															OO											
% CIPIC EMISS/ CIWASTE INPUT															OO											
PIC : POHC RATIO											OO							OO								

Table 4.7

Statistical Analysis of PIC Data from the IRF Pilot Facility during SF8 testing

CONFIDENCE INTEBVALS (CI):

'OO' = > or = 90% (inverse relation)
'O' = 80 - 90% (inverse relation)
'++' = > or = 90% (direct relation)
'+' = 80 - 90% (direct relation)
blank = no significant relation
NA = not attempted

	TEMP PRIM °C	TEMP SEC °C	FLOW SEC dscmm	FLOW STK dscmm	O2 PRIM %	O2 SEC %	O2 STK dry, %	CO PRIM ppm	NOx PRIM ppm	PART STK mg/dscm	ClPOHC FEED g/min	HCl STK mg/dscm	WASTE -vs- FUEL ratio	BZ EMISS RATE ug/min	BZ EMISS CONC ug/dscm	BZ EMISS CONC 10% O2	% BZ EMISS /POHC inp	% BZ EMISS /WASTE inp
TOT PIC EMISS RATE (ug/min)																		
TOT PIC EMISS CONC (ug/dscm)												+						
TOT PIC EMISS CONC (10% O2)	O		O															
% PIC EMISS / POHC INPUT												+						
% PIC EMISS / WASTE INPUT												+						
TOT ClPIC EMISS RATE (ug/min)																		
TOT ClPIC EMISS CONC (ug/dscm)	O		O															
TOT ClPIC EMISS CONC (10% O2)	O	O	O										++				O	O
% ClPIC EMISS / ClPOHC INPUT	O																	
% ClPIC EMISS / ClWASTE INPUT	O																	
PIC : POHC RATIO	OO	OO	OO										++					
CH3Cl EMISS RATE (ug/min)					O					+								
CH3Cl EMISS CONC (ug/dscm)					OO													
CH3Cl EMISS CONC (10% O2)			O							+								
% CH3Cl EMISS / POHC INPUT					O													
% CH3CL EMISS / WASTE INPUT					O													
BZ EMISS RATE (ug/min)		++	+	++		OO			O				OO	NA	NA	NA	NA	NA
BZ EMISS CONC (ug/dscm)		++	+	++		OO							OO	NA	NA	NA	NA	NA
BZ EMISS CONC (10% O2)		++		++	+	OO		O	O		O		OO	NA	NA	NA	NA	NA
% BZ EMISS / POHC INPUT		++	+	+		OO		O					OO	NA	NA	NA	NA	NA
% BZ EMISS / WASTE INPUT		++	+	+		OO		O					OO	NA	NA	NA	NA	NA

Table 4.8

Statistical Analysis of PIC Data from the IRF Pilot Facility during testing of 1,2,4-Trichlorobenzene and Hexachlorobenzene

CONFIDENCE INTERVALS (CI):

'OO' = > or = 90% (inverse relation)
'O' = 80 - 90% (inverse relation)
'++' = > or = 90% (direct relation)
'+' = 80 - 90% (direct relation)
blank = no significant relation
NA = not attempted

	TEMP KILN °C	TEMP AB °C	RT AB s	FLOW KILN dscmm	FLOW AB dscmm	O2 AB %	WASTE -vs- FUEL ratio
TOT PIC EMISS RATE (ug/min)							OO
TOT PIC EMISS CONC (ug/dscm)			+		O		O
TOT PIC EMISS CONC (10% O2)	O	OO	++		OO	++	OO
% PIC EMISS / POHC INPUT	O	O				++	++
% PIC EMISS / WASTE INPUT							
PIC : POHC RATIO	++	+			+		O
CLBZ EMISS RATE (ug/min)							OO
CLBZ EMISS CONC (ug/dscm)		O	++		OO		O
CLBZ EMISS CONC (10% O2)	O	OO	++		OO	++	
% CLBZ EMISS / POHC INPUT		OO	++		OO	++	+
1,3-DICLBZ EMISS RATE (ug/min)							OO
1,3-DICLBZ EMISS CONC (ug/dscm)							OO
1,3-DICLBZ EMISS CONC (10% O2)			+		O	+	OO
% 1,3-DICLBZ EMISS / POHC INPUT		OO	++		OO	++	

Table 4.9
Statistical Analysis of PIC Data from Acurex Boiler Study Site D

CONFIDENCE INTERVALS (CI):

'OO' = > or = 90% (inverse relation)
'O' = 80 - 90% (inverse relation)
'++' = > or = 90% (direct relation)
'+' = 80 - 90% (direct relation)
blank = no significant relation
NA = not attempted

	TEMP FURN °C	RT FURN s	FLOW STK dscfm	O2 BOILER %	O2 STK dry, %	CO STK ppm	NOx PRIM ppm	PART STK g/sec	ClPOHC FEED g/min	HCl STK g/sec	LOAD MMBtu/hr	# POHCS	Cl TO C8 HC	BZ EMISS RATE ug/min	BZ EMISS CONC ug/dscm	BZ EMISS CONC 10% O2	% BZ EMISS /POHC Inp	% BZ EMISS WASTE Inp	TOL EMISS RATE ug/min	TOL EMISS CONC ug/dscm	TOL EMISS CONC 10% O2	% TOL EMISS /POHC Inp	% TOL EMISS WASTE Inp	BZ+TOL EMISS RATE ug/min	BZ+TOL EMISS CONC ug/dscm	BZ+TOL EMISS CONC 10% O2	% BZ+TOL EMISS /POHC Inp	% BZ+TOL EMISS WASTE Inp
TOT PIC EMISS RATE (ug/min)		O	+	O	O		++			+	+	O																
TOT PIC EMISS CONC (ug/dscm)				O																								
TOT PIC EMISS CONC (10% O2)				O																								
% PIC EMISS / POHC INPUT		O	+				+		+	+	+	O														O		
% PIC EMISS / WASTE INPUT			+	OO			+			+	+															O		
TOT ClPIC EMISS RATE (ug/min)			+	OO			+			+	+															O		
TOT ClPIC EMISS CONC (ug/dscm)													+											O	O	O		
TOT ClPIC EMISS CONC (10% O2)													+											O	O	O		
% ClPIC EMISS / ClPOHC INPUT													++			O		O	O				O	OO	OO	OO	OO	O
% ClPIC EMISS / ClWASTE INPUT													++			O		O	O				O	OO	OO	OO	OO	O
PIC : POHC RATIO				O									+						O	OO	OO	OO	OO	O	OO	OO	OO	OO
DCM EMISS RATE (ug/min)			O	OO			+			+	+															O		
DCM EMISS CONC (ug/dscm)				O																			O			OO		O
DCM EMISS CONC (10% O2)				O																					O	O		
% DCM EMISS / POHC INPUT													++			O		O						OO	OO	O	O	
% DCM EMISS / WASTE INPUT													++			O		O						OO	OO	O	O	
1,1-DCE EMISS RATE (ug/min)				OO			+																					
1,1-DCE EMISS CONC (ug/dscm)																												
1,1-DCE EMISS CONC (10% O2)																												
% 1,1-DCE EMISS / POHC INPUT													+											O	O	O		
% 1,1-DCE EMISS / WASTE INPUT													+											O	O	O		
BZ EMISS RATE (ug/min)		O	++		OO		+	++	++	++	++	O	O	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BZ EMISS CONC (ug/dscm)		O	++		OO		+	++	++	++	++	O	O	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BZ EMISS CONC (10% O2)			+		OO			++	++	+	+		OO	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
% BZ EMISS / POHC INPUT		O	++		OO		+	++	++	++	++	O	O	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
% BZ EMISS / WASTE INPUT			+		OO			++	++	+	+		OO	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
TOL EMISS RATE (ug/min)						+							O	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
TOL EMISS CONC (ug/dscm)				+										NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
TOL EMISS CONC (10% O2)				+										NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
% TOL EMISS / POHC INPUT				+										NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
% TOL EMISS / WASTE INPUT														NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table 4.10
Statistical Analysis of PIC Data from Acurex Boiler Study Site E

CONFIDENCE INTERVALS (CI):

'OO' = > or = 90% (inverse relation)
'O' = 80 - 90% (inverse relation)
'↔' = > or = 90% (direct relation)
'+' = 80 - 90% (direct relation)
blank = no significant relation
NA = not attempted

	TEMP FURN °C	TEMP BOIL °C	TEMP ECON °C	FLOW STK dscfm	O2 BOILER %	O2 STK dry, %	CO STK ppm	NOx PRIM ppm	PART STK g/sec	ClPOHC FEED g/min	HCl STK g/sec	LOAD MBtu/hr	WASTE↔FUEL ratio	# POHCS	Cl TO C6 HC	BZ EMISS RATE ug/min	BZ EMISS CONC ug/dscm	BZ EMISS CONC 10% O2	% BZ EMISS /POHC Inp	% BZ EMISS WASTE Inp	TOL EMISS RATE ug/min	TOL EMISS CONC ug/dscm	TOL EMISS CONC 10% O2	% TOL EMISS /POHC Inp	% TOL EMISS WASTE Inp	BZ+TOL EMISS RATE ug/min	BZ+TOL EMISS CONC ug/dscm	BZ+TOL EMISS CONC 10% O2	% BZ+TOL EMISS /POHC Inp	% BZ+TOL EMISS WASTE Inp
TOT PIC EMISS RATE (ug/min)				↔									O				+	+	+	+										+
TOT PIC EMISS CONC (ug/dscm)	+			+									O																	+
TOT PIC EMISS CONC (10% O2)	+			+									O																	+
% PIC EMISS / POHC INPUT	↔		+																											
% PIC EMISS /WASTE INPUT													O																	
TOT ClPIC EMISS RATE (ug/min)				↔									O																	
TOT ClPIC EMISS CONC (ug/dscm)				+									OO			+	+	+	+	+										+
TOT ClPIC EMISS CONC (10% O2)				+									O			+	+	+	+	+										+
% ClPIC EMISS / ClPOHC INPUT																														
% ClPIC EMISS / ClWASTE INPUT																														
PIC : POHC RATIO	↔			↔								↔																		
CHCL3 EMISS RATE (ug/min)																↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔
CHCL3 EMISS CONC (ug/dscm)																↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔
CHCL3 EMISS CONC (10% O2)																↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔
% CHCL3 EMISS / POHC INPUT											+			↔		↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔
% CHCL3 EMISS / WASTE INPUT											+			↔		↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔
PCA EMISS RATE (ug/min)							O						OO			↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔
PCA EMISS CONC (ug/dscm)							O						OO			↔	↔	↔	+	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔
PCA EMISS CONC (10% O2)													O		O	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔
% PCA EMISS / POHC INPUT					O								O																	
% PCA EMISS / WASTE INPUT					O								O																	
BZ EMISS RATE (ug/min)					↔	↔								+		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BZ EMISS CONC (ug/dscm)					↔	↔										NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BZ EMISS CONC (10% O2)					↔	↔										NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
% BZ EMISS / POHC INPUT				+	↔	↔								+		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
% BZ EMISS /WASTE INPUT					↔	↔										NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
TOL EMISS RATE (ug/min)							O						OO			NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
TOL EMISS CONC (ug/dscm)							O						OO			NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
TOL EMISS CONC (10% O2)							O						OO			NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
% TOL EMISS / POHC INPUT						+										NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
% TOL EMISS /WASTE INPUT							O						OO			NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table 4.11
Statistical Analysis of PIC Data from Acurex Boiler Study Site F

CONFIDENCE INTERVALS (CI):

'OO' = > or = 90% (inverse relation)
'O' = 80 - 90% (inverse relation)
'++' = > or = 90% (direct relation)
'+' = 80 - 90% (direct relation)
blank = no significant relation
NA = not attempted

	FLOW STK	O2 STK	NOx PRIM	PART STK	Cl POHC FEED	HCl STK	LOAD	WASTE -vs- FUEL	TOL EMISS RATE	TOL EMISS CONC	TOL EMISS CONC	% TOL EMISS	% TOL EMISS
	dscfm	dry, %	ppm	g/sec	g/min	g/sec	MBtu/hr	rat.	ug/min	ug/dscm	10% O2	/POHC inp	/WASTE inp
TOT PIC EMISS RATE (ug/min)													
TOT PIC EMISS CONC (ug/dscm)													
TOT PIC EMISS CONC (10% O2)													
TOT CIPIC EMISS RATE (ug/min)													
TOT CIPIC EMISS CONC (ug/dscm)													
TOT CIPIC EMISS CONC (10% O2)													
TOL EMISS RATE (ug/min)									NA	NA	NA	NA	NA
TOL EMISS CONC (ug/dscm)									NA	NA	NA	NA	NA
TOL EMISS CONC (10% O2)									NA	NA	NA	NA	NA
% TOL EMISS / POHC INPUT									NA	NA	NA	NA	NA
% TOL EMISS / WASTE INPUT									NA	NA	NA	NA	NA

Table 4.12
Statistical Analysis of PIC Data from Acurex Kiln: Study Site 2

CONFIDENCE INTERVALS (CI):

'OO' = > or = 90% (inverse relation)
'O' = 80 - 90% (inverse relation)
'++' = > or = 90% (direct relation)
'+' = 80 - 90% (direct relation)
blank = no significant relation

	TEMP STK °C	FLOW STK dscfm	O2 STK dry, %	NOx PRIM ppm	PART STK g/sec	HCl STK g/sec	Cl SCRBB OUT mg/L	Cl OUT -vs- Cl IN SCRUB ratio	WASTE -vs- FUEL ratio	BZ EMISS RATE ug/min	BZ EMISS CONC ug/dscm	BZ EMISS CONC 10% O2	% BZ EMISS /POHC Inp	% BZ EMISS WASTE Inp	TOL EMISS RATE ug/min	TOL EMISS CONC ug/dscm	TOL EMISS CONC 10% O2	% TOL EMISS /POHC Inp	% TOL EMISS WASTE Inp	BZ+TOL EMISS RATE ug/min	BZ+TOL EMISS CONC ug/dscm	BZ+TOL EMISS CONC 10% O2	% BZ+TOL EMISS /POHC Inp	% BZ+TOL EMISS WASTE Inp
TOT PIC EMISS RATE (ug/min)			OO										OO			++	++	++			+			
TOT PIC EMISS CONC (ug/dscm)			OO										OO			++	++	++			+			
TOT PIC EMISS CONC (10% O2)			OO										OO			++	++	++			+			
% PIC EMISS / POHC INPUT			OO										OO			++	++	++			+			
% PIC EMISS / WASTE INPUT																								
TOT ClPIC EMISS RATE (ug/min)			OO										OO			++	++	++			+			
TOT ClPIC EMISS CONC (ug/dscm)			OO										OO			++	++	++			+			
TOT ClPIC EMISS CON (10% O2)			OO										OO			++	++	++			+			
% ClPIC EMISS / ClPOHC INPUT			OO										OO			++	++	++			+			
% ClPIC EMISS / ClWASTE INPUT			OO										OO			++	++	++			+			
PIC : POHC RATIO					OO					OO														
CH3CL EMISS RATE (ug/min)			OO										OO			++	++	++			+			
CH3CL EMISS CONC (ug/dscm)			OO										OO			++	++	++			+			
CH3CL EMISS CON (10% O2)			OO										OO			++	++	++			+			
% CH3CL EMISS / POHC INPUT			OO										OO			++	++	++			+			
% CH3CL EMISS / WASTE INPUT			OO										OO			++	++	++			+			
C2H3CL EMISS RATE (ug/min)																								
C2H3CL EMISS CONC (ug/dscm)																								
C2H3CL EMISS CONC (10% O2)																								
% C2H3CL EMISS / POHC INPUT																								
% C2H3CL EMISS / WASTE INPUT																								
TOL EMISS RATE (ug/min)							++	++	+	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
TOL EMISS CONC (ug/dscm)			OO							NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
TOL EMISS CONC (10% O2)			OO							NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
% TOL EMISS / POHC INPUT			OO							NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
% TOL EMISS / WASTE INPUT							++	++	+	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BZ EMISS RATE (ug/min)	+				+					NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BZ EMISS CONC (ug/dscm)				OO		OO			+	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BZ EMISS CONC (10% O2)										NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
% BZ EMISS / POHC INPUT			++							NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
% BZ EMISS / WASTE INPUT				OO		OO			+	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Both positive and negative correlations at the 80 and 90% (confidence level) are indicated.

It should be noted that there were a number of strong statistical correlations that appeared to be "accidental", i.e., there was no correlation between other variables which appeared to be intrinsically related. Most importantly, the data often appeared to be of poor quality and somewhat unreliable for measurement of some specific PIC emission quantities. Thus, to aid identification of key correlations, a technique was used where correlation between a given independent parameter and any PIC emission variable were searched for. This information is readily available from Tables 4.3 - 4.12 and helps to eliminate many of the apparent inconsistencies due to poor data quality.

In the following paragraphs, we discuss significant observations for each class of facility included in the study: full-scale and pilot-scale incinerators, co-fired boilers, and co-fired kilns.

Full-Scale Hazardous Waste Incinerators

Four incineration facilities were included in the data base with one facility being studied under two sets of conditions (failure and optimal operation), bringing the total number of studies to 5. Table 4.13 presents a summary of the number of successful correlations per number of attempts for which a number of statistically significant data points were available (e.g., 2/4 means two correlations for four facilities that have the necessary 4 or more data points). One asterisk above the entry denotes a negative correlation while 2 asterisks denotes that both positive and negative correlations were observed.

In general, there were not many successful correlations for the hazardous waste incinerators (see Tables 4.3-4.6, 4.13). None of the measured temperatures or residence times of the different zones correlated with any measure of PIC emissions on a consistent basis. The available data base was inadequate to draw conclusions about the correlation of PIC emissions with

Table 4.13
Summary of Statistical Correlation Results for Full-Scale Hazardous Waste Incinerators

KEY:
blank = not attempted,
otherwise, # correlations / # attempts

* indicates ' - ' correlation coefficient
** denotes that there were ' + ' and ' - ' correlation coefficients

	TEMP PRIM °C	TEMP SEC °C	TEMP QNCH °C	TEMP APCD °C	TEMP STK °C	TEMP AB °C	TEMP KILN °C	TEMP FURN °C	TEMP BOIL °C	TEMP ECON °C	RT FURN s	RT SEC s	RT AB s	RT TOTAL s	FLOW STK dscmm	FLOW STK dscmm	FLOW AB dscmm
TOT PIC EMISS RATE (ug/min)	0/4	1/4*	0/1	0/2	0/5							0/1		0/3		1/5	
TOT PIC EMISS CONC (ug/dscm)	0/4	0/4	0/1	0/2	0/5							0/1		0/3		1/5	
TOT PIC EMISS CONC (10% O2)	0/4	0/4	0/1	0/2	0/5							0/1		0/3		1/5	
% PIC EMISS / POHC INPUT	0/4	1/4	0/1	0/2	0/5							0/1		0/3		0/5	
% PIC EMISS / WASTE INPUT	0/4	1/4	0/1	0/2	0/5							0/1		0/3		1/5	
TOT CIPIC EMISS RATE (ug/min)	0/3	0/3		0/2	0/4							1/1		0/2		0/4	
TOT CIPIC EMISS CONC (ug/dscm)	0/3	0/3		0/2	0/4							1/1		0/2		0/4	
TOT CIPIC EMISS CON (10% O2)	0/3	0/3		0/2	0/4							1/1		0/2		0/4	
% CIPIC EMISS / CIPOHC INPUT	1/3	1/3		0/2	0/4							0/1		0/2		0/4	
% CIPIC EMISS / CIWASTE INPUT	0/3	1/3		0/2	0/4							1/1		0/2		0/4	
PIC : POHC RATIO	0/4	2/4**	0/1	0/2	0/5							0/2		0/3		0/5	
BZ EMISS RATE (ug/min)	0/2	0/2		0/1	0/3							0/1		0/1		0/3	
BZ EMISS CONC (ug/dscm)	0/2	0/2		0/1	0/3							0/1		0/1		0/3	
BZ EMISS CCNC (10% O2)	0/2	0/2		0/1	0/3							0/1		0/1		0/3	
% BZ EMISS / POHC INPUT	0/2	0/2		0/1	0/3							0/1		0/1		0/3	
% BZ EMISS / WASTE INPUT	0/2	0/2		0/1	0/3							0/1		0/1		0/3	
TOL EMISS RATE (ug/min)	0/2	0/2		0/1	0/3							0/1		0/1		0/3	
TOL EMISS CONC (ug/dscm)	0/2	0/2		0/1	0/3							0/1		0/1		0/3	
TOL EMISS CONC (10% O2)	0/2	0/2		0/1	0/3							0/1		0/1		0/3	
% TOL EMISS / POHC INPUT	0/2	0/2		1/1	1/3							0/1		0/1		0/3	
% TOL EMISS / WASTE INPUT	0/2	0/2		0/1	0/3							0/1		0/1		0/3	
CHCl3 EMISS RATE (ug/min)	0/1	0/1			0/2							0/1		0/1		0/2	
CHCl3 EMISS CONC (ug/dscm)	0/1	0/1			0/2							0/1		0/1		0/2	
CHCl3 EMISS CONC (10% O2)	0/1	0/1			1/2							0/1		0/1		0/2	
% CHCl3 EMISS / POHC INPUT	0/1	0/1			0/2							0/1		0/1		0/2	
% CHCl3 EMISS / WASTE INPUT	0/1	0/1			0/2							0/1		0/1		0/2	
CH3Cl EMISS RATE (ug/min)	0/1	0/1		0/1	0/1											0/1	
CH3Cl EMISS CONC (ug/dscm)	0/1	0/1		0/1	0/1											0/1	
CH3Cl EMISS CONC (10% O2)	0/1	0/1		0/1	0/1											0/1	
% CH3Cl EMISS / POHC INPUT	0/1	0/1		1/1	1/1											0/1	
% CH3Cl EMISS / WASTE INPUT	0/1	0/1		1/1	1/1												
CH2CL2 EMISS RATE (ug/min)																	
CH2CL2 EMISS CONC (ug/dscm)																	
CH2CL2 EMISS CONC (10% O2)																	
% CH2CL2 EMISS / POHC INPUT																	
% CH2CL2 EMISS / WASTE INPUT																	
1,3-DICLBZ EMISS RATE (ug/min)																	
1,3-DICLBZ EMISS CONC (ug/dscm)																	
1,3-DICLBZ EMISS CONC (10% O2)																	
% 1,3-DICLBZ EMISS / POHC INPUT																	
% 1,3-DICLBZ EMISS / WASTE INPUT																	
CLBZ EMISS RATE (ug/min)																	
CLBZ EMISS CONC (ug/dscm)																	
CLBZ EMISS CONC (10% O2)																	
% CLBZ EMISS / POHC INPUT																	
% CLBZ EMISS / WASTE INPUT																	
TCE EMISS RATE (ug/min)					0/1									0/1		0/1	
TCE EMISS CONC (ug/dscm)					0/1									0/1		0/1	
TCE EMISS CONC (10% O2)					0/1									0/1		0/1	
% TCE EMISS / POHC INPUT					0/1									0/1		0/1	
% TCE EMISS / WASTE INPUT					0/1									0/1		0/1	
PCA EMISS RATE (ug/min)																	
PCA EMISS CONC (ug/dscm)																	
PCA EMISS CONC (10% O2)																	
% PCA EMISS / POHC INPUT																	
% PCA EMISS / WASTE INPUT																	
1,1,1-TCA EMISS RATE (ug/min)	0/1	0/1			0/1							0/1		0/1		0/1	
1,1,1-TCA EMISS CONC (ug/dscm)	1/1*	0/1			0/1							0/1		0/1		0/1	
1,1,1-TCA EMISS CONC (10% O2)	1/1*	0/1			0/1							0/1		0/1		0/1	
% 1,1,1-TCA EMISS / POHC INPUT	0/1	0/1			0/1							0/1		0/1		0/1	
% 1,1,1-TCA EMISS / WASTE INPUT	0/1	0/1			0/1							0/1		0/1		0/1	
1,1-DCE EMISS RATE (ug/min)																	
1,1-DCE EMISS CONC (ug/dscm)																	
1,1-DCE EMISS CONC (10% O2)																	
% 1,1-DCE EMISS / POHC INPUT																	
% 1,1-DCE EMISS / WASTE INPUT																	
VC EMISS RATE (ug/min)																	
VC EMISS CONC (ug/dscm)																	
VC EMISS CONC (10% O2)																	
% VC EMISS / POHC INPUT																	
% VC EMISS / WASTE INPUT																	

Table 4.13, cont.
Summary of Statistical Correlation Results for Full-Scale Hazardous Waste Incinerators

KEY:
blank = not attempted,
otherwise, # correlations / # attempts

* indicates '-' correlation coefficient
** denotes that there were '+' and '-' correlation coefficients

	FLOW KILN dscmm	O2 PRIM %	O2 SEC %	O2 STK dry,%	O2 AB OUT %	O2 KILN OUT %	O2 BOILER %	CO PRIM ppm	CO STK ppm	CO KILN ppm	NOx PRIM ppm	TUHC COLD ppm,3% O2	TUHC HOT ppm,3% O2	PART STK g/sec	PART STK mg/dscm	PART APCD g/dscm
TOT PIC EMISS RATE (ug/min)				0/5					0/4			0/3	0/1	0/4		0/4
TOT PIC EMISS CONC (ug/dscm)				0/5					1/4*			0/3	0/1	0/4		0/4
TOT PIC EMISS CONC (10% O2)				0/5					1/4*			0/3	0/1	0/4		0/4
% PIC EMISS / POHC INPUT				0/5					1/4*			0/3	0/1	0/4		0/4
% PIC EMISS / WASTE INPUT				0/5					1/4*			0/3	0/1	0/4		0/4
TOT ClPIC EMISS RATE (ug/min)				2/4					0/3			1/3	0/1	0/4		0/4
TOT ClPIC EMISS CONC (ug/dscm)				2/4					0/3			1/3	0/1	0/4		0/4
TOT ClPIC EMISS CON (10% O2)				2/4					0/3			1/3	0/1	0/4		0/4
% ClPIC EMISS / ClPOHC INPUT				1/4					0/3			0/3	0/1	0/4		0/4
% ClPIC EMISS / ClWASTE INPUT				2/4					0/3			1/3	0/1	0/4		0/4
PIC : POHC RATIO				0/5					0/4			0/3	0/1	0/4		0/4
BZ EMISS RATE (ug/min)				0/3					0/2			0/2	0/1	0/3		0/3
BZ EMISS CONC (ug/dscm)				1/3					0/2			0/2	0/1	0/3		0/3
BZ EMISS CONC (10% O2)				1/3					0/2			0/2	0/1	0/3		0/3
% BZ EMISS / POHC INPUT				0/3					0/2			0/2	0/1	0/3		0/3
% BZ EMISS / WASTE INPUT				1/3					0/2			0/2	0/1	0/3		0/3
TOL EMISS RATE (ug/min)				0/3					0/2			0/2	0/1	0/3		0/3
TOL EMISS CONC (ug/dscm)				0/3					0/2			0/2	0/1	0/3		0/3
TOL EMISS CONC (10% O2)				0/3					0/2			0/2	0/1	0/3		0/3
% TOL EMISS / POHC INPUT				1/3*					0/2			0/2	0/1	0/3		1/3
% TOL EMISS / WASTE INPUT				0/3					0/2			0/2	0/1	0/3		0/3
CHCl3 EMISS RATE (ug/min)				0/2					0/1			0/1		0/2		0/2
CHCl3 EMISS CONC (ug/dscm)				0/2					0/1			0/1		0/2		0/2
CHCl3 EMISS CONC (10% O2)				0/2					0/1			0/1		0/2		0/2
% CHCl3 EMISS / POHC INPUT				0/2					0/1			0/1		0/2		0/2
% CHCl3 EMISS / WASTE INPUT				0/2					0/1			0/1		0/2		0/2
CH3Cl EMISS RATE (ug/min)				1/1*					0/1			0/1	0/1	1/1		1/1
CH3Cl EMISS CONC (ug/dscm)				1/1*					0/1			0/1	0/1	0/1		0/1
CH3Cl EMISS CONC (10% O2)				0/1					0/1			0/1	0/1	0/1		0/1
% CH3Cl EMISS / POHC INPUT				1/1*					0/1			0/1	0/1	1/1		1/1
% CH3Cl EMISS / WASTE INPUT				0/1					0/1			0/1	0/1	1/1		1/1
CH2CL2 EMISS RATE (ug/min)																
CH2CL2 EMISS CONC (ug/dscm)																
CH2CL2 EMISS CONC (10% O2)																
% CH2CL2 EMISS / POHC INPUT																
% CH2CL2 EMISS / WASTE INPUT																
1,3-DICLBZ EMISS RATE (ug/min)																
1,3-DICLBZ EMISS CONC (ug/dscm)																
1,3-DICLBZ EMISS CONC (10% O2)																
% 1,3-DICLBZ EMISS / POHC INPUT																
% 1,3-DICLBZ EMISS / WASTE INPUT																
CLBZ EMISS RATE (ug/min)																
CLBZ EMISS CONC (ug/dscm)																
CLBZ EMISS CONC (10% O2)																
% CLBZ EMISS / POHC INPUT																
% CLBZ EMISS / WASTE INPUT																
TCE EMISS RATE (ug/min)				0/1										0/1		0/1
TCE EMISS CONC (ug/dscm)				0/1										0/1		0/1
TCE EMISS CONC (10% O2)				0/1										0/1		0/1
% TCE EMISS / POHC INPUT				0/1										0/1		0/1
% TCE EMISS / WASTE INPUT				0/1										0/1		0/1
PCA EMISS RATE (ug/min)																
PCA EMISS CONC (ug/dscm)																
PCA EMISS CONC (10% O2)																
% PCA EMISS / POHC INPUT																
% PCA EMISS / WASTE INPUT																
1,1,1-TCA EMISS RATE (ug/min)				0/1					0/1			0/1		0/1		0/1
1,1,1-TCA EMISS CONC (ug/dscm)				0/1					0/1			0/1		0/1		0/1
1,1,1-TCA EMISS CONC (10% O2)				0/1					0/1			0/1		0/1		0/1
% 1,1,1-TCA EMISS / POHC INPUT				0/1					0/1			0/1		0/1		0/1
% 1,1,1-TCA EMISS / WASTE INPUT				0/1					0/1			0/1		0/1		0/1
1,1-DCE EMISS RATE (ug/min)																
1,1-DCE EMISS CONC (ug/dscm)																
1,1-DCE EMISS CONC (10% O2)																
% 1,1-DCE EMISS / POHC INPUT																
% 1,1-DCE EMISS / WASTE INPUT																
VC EMISS RATE (ug/min)																
VC EMISS CONC (ug/dscm)																
VC EMISS CONC (10% O2)																
% VC EMISS / POHC INPUT																
% VC EMISS / WASTE INPUT																

Table 4.13, cont.
Summary of Statistical Correlation Results for Full-Scale Hazardous Waste Incinerators

KEY:
blank = not attempted,
otherwise, # correlations / # attempts

* indicates '-' correlation coefficient
** denotes that there were '+' and '-' correlation coefficients

	APCD EFFIC %	Cl POHC FEED g/min	HCl STK mg/dscm	Cl SCRBS IN mg/L	Cl SCRBS OUT mg/L	Cl OUT -vs- Cl IN SCRUB ratio	LOAD MBtu/hr	LOAD lb/hr	WASTE -vs- FUEL ratio	# POHCS	Cl TO C8 HC	BZ EMISS RATE ug/min	BZ EMISS CONC ug/dscm	BZ EMISS CONC 10% O2
TOT PIC EMISS RATE (ug/min)	0/1	0/5	1/4	0/1	0/1	0/1	1/5	0/3	0/2	0/1		1/3	1/3	1/3
TOT PIC EMISS CONC (ug/dscm)	0/1	0/5	1/4	0/1	0/1	0/1	1/5	0/3	0/2	0/1		1/3	1/3	1/3
TOT PIC EMISS CONC (10% O2)	0/1	0/5	0/4	0/1	0/1	0/1	2/5	0/3	0/2	0/1		1/3	1/3	1/3
% PIC EMISS / POHC INPUT	0/1	0/5	0/4	0/1	0/1	0/1	1/5	0/3	0/2	0/1		0/3	0/3	0/3
% PIC EMISS / WASTE INPUT	0/1	0/5	0/4	0/1	0/1	0/1	1/5	0/3	1/1*	0/1		1/3	2/3	2/3
TOT ClPIC EMISS RATE (ug/min)	0/1	0/4	0/4	0/1	0/1	0/1	0/4	0/3	1/2*	0/1		0/3	1/3	1/3
TOT ClPIC EMISS CONC (ug/dscm)	0/1	0/4	0/4	0/1	0/1	0/1	0/4	0/3	1/2*	0/1		0/3	1/3	1/3
TOT ClPIC EMISS CON (10% O2)	0/1	0/4	0/4	0/1	0/1	0/1	0/4	0/3	1/2*	0/1		0/3	2/3	2/3
% ClPIC EMISS / ClPOHC INPUT	0/1	0/4	0/4	0/1	0/1	0/1	0/4	0/3	1/2*	0/1		1/3	2/3	2/3
% ClPIC EMISS / ClWASTE INPUT	0/1	0/4	0/4	0/1	0/1	0/1	0/4	0/3	1/2*	0/1		0/3	1/3	1/3
PIC : POHC RATIO	0/1	1/5*	0/4	0/1	0/1	0/1	0/5	0/3	0/2	0/1		1/3	0/3	0/3
BZ EMISS RATE (ug/min)	1/1	0/3	0/3	1/1	1/1	1/1	1/3	1/3	1/1					
BZ EMISS CONC (ug/dscm)	0/1	0/3	0/3	0/1	0/1	0/1	0/3	0/3	0/1					
BZ EMISS CONC (10% O2)	0/1	0/3	0/3	0/1	0/1	0/1	0/3	0/3	0/1					
% BZ EMISS / POHC INPUT	0/1	0/3	0/3	0/1	0/1	0/1	0/3	1/3	0/1					
% BZ EMISS / WASTE INPUT	0/1	0/3	1/3	0/1	0/1	0/1	0/3	1/3	0/1					
TOL EMISS RATE (ug/min)	0/1	0/3	0/3	0/1	0/1	1/1	0/3	0/3	0/1					
TOL EMISS CONC (ug/dscm)	0/1	0/3	0/3	0/1	0/1	1/1	0/3	0/3	0/1					
TOL EMISS CONC (10% O2)	0/1	0/3	0/3	0/1	0/1	1/1	0/3	0/3	0/1					
% TOL EMISS / POHC INPUT	1/1	0/3	0/3	1/1*	0/1	0/1	0/3	0/3	0/1					
% TOL EMISS / WASTE INPUT	0/1	0/3	0/3	1/1	0/1	0/1	0/3	0/3	0/1					
CHCl3 EMISS RATE (ug/min)		0/2	0/2				0/2	0/2				0/2	0/2	0/2
CHCl3 EMISS CONC (ug/dscm)		0/2	0/2				0/2	0/2				0/2	0/2	0/2
CHCl3 EMISS CONC (10% O2)		0/2	0/2				0/2	0/2				0/2	0/2	0/2
% CHCl3 EMISS / POHC INPUT		0/2	0/2				0/2	0/2				0/2	0/2	0/2
% CHCl3 EMISS / WASTE INPUT		0/2	0/2				0/2	0/2				0/2	0/2	0/2
CH3Cl EMISS RATE (ug/min)	0/1	0/1	0/1	0/1	0/1	0/1	1/1	0/1	0/1			0/1	0/1	0/1
CH3Cl EMISS CONC (ug/dscm)	0/1	0/1	0/1	0/1	0/1	0/1	1/1	0/1	0/1			0/1	0/1	0/1
CH3Cl EMISS CONC (10% O2)	0/1	0/1	0/1	0/1	0/1	0/1	1/1	0/1	0/1			0/1	0/1	0/1
% CH3Cl EMISS / POHC INPUT	0/1	0/1	0/1	0/1	0/1	0/1	1/1	0/1	0/1			0/1	0/1	0/1
% CH3Cl EMISS / WASTE INPUT	0/1	0/1	0/1	0/1	0/1	0/1	1/1	0/1	0/1			0/1	0/1	0/1
CH2CL2 EMISS RATE (ug/min)														
CH2CL2 EMISS CONC (ug/dscm)														
CH2CL2 EMISS CONC (10% O2)														
% CH2CL2 EMISS / POHC INPUT														
% CH2CL2 EMISS / WASTE INPUT														
1,3-DICLBZ EMISS RATE (ug/min)														
1,3-DICLBZ EMISS CONC (ug/dscm)														
1,3-DICLBZ EMISS CONC (10% O2)														
% 1,3-DICLBZ EMISS / POHC INPUT														
% 1,3-DICLBZ EMISS / WASTE INPUT														
CLBZ EMISS RATE (ug/min)														
CLBZ EMISS CONC (ug/dscm)														
CLBZ EMISS CONC (10% O2)														
% CLBZ EMISS / POHC INPUT														
% CLBZ EMISS / WASTE INPUT														
TCE EMISS RATE (ug/min)		0/1	0/1				0/1	0/1				0/1	0/1	0/1
TCE EMISS CONC (ug/dscm)		0/1	0/1				0/1	0/1				0/1	0/1	0/1
TCE EMISS CONC (10% O2)		0/1	0/1				0/1	0/1				0/1	0/1	0/1
% TCE EMISS / POHC INPUT		0/1	0/1				0/1	0/1				0/1	0/1	0/1
% TCE EMISS / WASTE INPUT		0/1	0/1				0/1	0/1				0/1	0/1	0/1
PCA EMISS RATE (ug/min)														
PCA EMISS CONC (ug/dscm)														
PCA EMISS CONC (10% O2)														
% PCA EMISS / POHC INPUT														
% PCA EMISS / WASTE INPUT														
1,1,1-TCA EMISS RATE (ug/min)		0/1	0/1				0/1	0/1				0/1	0/1	0/1
1,1,1-TCA EMISS CONC (ug/dscm)		0/1	0/1				0/1	0/1				0/1	0/1	0/1
1,1,1-TCA EMISS CONC (10% O2)		0/1	0/1				0/1	0/1				0/1	0/1	0/1
% 1,1,1-TCA EMISS / POHC INPUT		0/1	0/1				0/1	0/1				0/1	0/1	0/1
% 1,1,1-TCA EMISS / WASTE INPUT		0/1	0/1				0/1	0/1				0/1	0/1	0/1
1,1-DCE EMISS RATE (ug/min)														
1,1-DCE EMISS CONC (ug/dscm)														
1,1-DCE EMISS CONC (10% O2)														
% 1,1-DCE EMISS / POHC INPUT														
% 1,1-DCE EMISS / WASTE INPUT														
VC EMISS RATE (ug/min)														
VC EMISS CONC (ug/dscm)														
VC EMISS CONC (10% O2)														
% VC EMISS / POHC INPUT														
% VC EMISS / WASTE INPUT														

Table 4.15, cont.

Summary of Statistical Correlation Results for Full-Scale Hazardous Waste Incinerators

KEY:
blank = not attempted,
otherwise, # correlations / # attempts

* indicates '-' correlation coefficient
** denotes that there were '+' and '-' correlation coefficients

	% BZ EMISS /POHC inp	% BZ EMISS /WASTE inp	TOL EMISS RATE ug/min	TOL EMISS CONC ug/dscm	TOL EMISS CONC 10% O2	% TOL EMISS /POHC inp	% TOL EMISS /WASTE inp	BZ + TOL EMISS RATE ug/min	BZ + TOL EMISS CONC ug/dscm	BZ + TOL EMISS CONC 10% O2	% BZ+TOL EMISS /POHC inp	% BZ+TOL EMISS /WASTE inp
TOT PIC EMISS RATE (ug/min)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TOT PIC EMISS CONC (ug/dscm)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TOT PIC EMISS CONC (10% O2)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
% PIC EMISS / POHC INPUT	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
% PIC EMISS / WASTE INPUT	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TOT CIPIC EMISS RATE (ug/min)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TOT CIPIC EMISS CONC (ug/dscm)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TOT CIPIC EMISS CON (10% O2)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
% CIPIC EMISS / CIPOHC INPUT	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
% CIPIC EMISS / CIWASTE INPUT	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
PIC : POHC RATIO	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
BZ EMISS RATE (ug/min)												
BZ EMISS CONC (ug/dscm)												
BZ EMISS CONC (10% O2)												
% BZ EMISS / POHC INPUT												
% BZ EMISS / WASTE INPUT												
TOL EMISS RATE (ug/min)												
TOL EMISS CONC (ug/dscm)												
TOL EMISS CONC (10% O2)												
% TOL EMISS / POHC INPUT												
% TOL EMISS / WASTE INPUT												
CHCl3 EMISS RATE (ug/min)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
CHCl3 EMISS CONC (ug/dscm)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
CHCl3 EMISS CONC (10% O2)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
% CHCl3 EMISS / POHC INPUT	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
% CHCl3 EMISS / WASTE INPUT	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
CHBCl EMISS RATE (ug/min)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
CHBCl EMISS CONC (ug/dscm)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
CHBCl EMISS CONC (10% O2)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
% CHBCl EMISS / POHC INPUT	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
% CHBCl EMISS / WASTE INPUT	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
CHBCL2 EMISS RATE (ug/min)												
CHBCL2 EMISS CONC (ug/dscm)												
CHBCL2 EMISS CONC (10% O2)												
% CHBCL2 EMISS / POHC INPUT												
% CHBCL2 EMISS / WASTE INPUT												
1,3-DICLBZ EMISS RATE (ug/min)												
1,3-DICLBZ EMISS CONC (ug/dscm)												
1,3-DICLBZ EMISS CONC (10% O2)												
% 1,3-DICLBZ EMISS / POHC INPUT												
% 1,3-DICLBZ EMISS / WASTE INPUT												
CLBZ EMISS RATE (ug/min)												
CLBZ EMISS CONC (ug/dscm)												
CLBZ EMISS CONC (10% O2)												
% CLBZ EMISS / POHC INPUT												
% CLBZ EMISS / WASTE INPUT												
TCE EMISS RATE (ug/min)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TCE EMISS CONC (ug/dscm)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TCE EMISS CONC (10% O2)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
% TCE EMISS / POHC INPUT	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
% TCE EMISS / WASTE INPUT	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
PCA EMISS RATE (ug/min)												
PCA EMISS CONC (ug/dscm)												
PCA EMISS CONC (10% O2)												
% PCA EMISS / POHC INPUT												
% PCA EMISS / WASTE INPUT												
1,1,1-TCA EMISS RATE (ug/min)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1,1,1-TCA EMISS CONC (ug/dscm)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1,1,1-TCA EMISS CONC (10% O2)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
% 1,1,1-TCA EMISS / POHC INPUT	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
% 1,1,1-TCA EMISS / WASTE INPUT	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1,1-DCE EMISS RATE (ug/min)												
1,1-DCE EMISS CONC (ug/dscm)												
1,1-DCE EMISS CONC (10% O2)												
% 1,1-DCE EMISS / POHC INPUT												
% 1,1-DCE EMISS / WASTE INPUT												
VC EMISS RATE (ug/min)												
VC EMISS CONC (ug/dscm)												
VC EMISS CONC (10% O2)												
% VC EMISS / POHC INPUT												
% VC EMISS / WASTE INPUT												

regulatory PIC surrogates (e.g., CO, cold TUHC, or hot TUHC), and only weak correlations were observed.

Somewhat stronger correlations observed were those between the stack O_2 concentrations (O_2 stack, % dry) and the dependent variables associated with emission of chlorinated PICs (i.e., total CLPIC emission rate (µg/min), total CLPIC emission conc (µg/dscm), total CLPIC emission conc (corrected to 10% O_2) and %CLPIC emission/CL waste input). Stack O_2 concentration correlated consistently with these dependent variables for two of four incinerator studies for which data were available. Although still weak, it will be shown that this was an intermittent correlation observed for the other types of facilities as well.

Higher levels of O_2 in the stack may result in increased levels of PIC emissions through 3 identifiable mechanisms. One may be that higher rates of introduction of secondary air lower the temperature in zone 3 or rapidly quench the gases at the exit of zone 3. Second, higher levels of O_2 (air) may also reduce the residence time through increased gas flow rate. Since neither temperature nor residence time consistently correlated with PIC emissions, these explanations seem unlikely. A third explanation is that large quantities of O_2 in the stack indicate poor combustion when the waste/air mixing is poor. This hypothesis is at least partially supported by the occasional correlations between waste heat load (MBtu/hr) and total emissions which may be indicative of poor waste/air mixing in a partial overload situation.

There were some strong correlations between benzene and toluene emissions and total PIC emissions and chlorinated PIC emissions. The general trend was that correlations were improved when each parameter was normalized in some manner. For example, normalized benzene concentration in the stack correlated in 2 of 3 cases with the total PIC emission concentration (normalized to 10% O_2), %PIC emissions per waste input, total CLPIC emission concentration (corrected to 10% O_2) and % CLPIC emissions per chlorinated POHC input. However, only occasional weak correlations were observed for uncorrected emission rates of benzene and PICs.

Pilot-Scale Hazardous Waste Incinerators

Two studies at the EPA's Incineration Research Facility (IRF) were appropriate for inclusion in this data base. The summary results are shown in Table 4.14 while correlations for the two separate studies are shown in Tables 4.7 and 4.8. In general, stronger correlations were observed in these studies than in the full-scale studies because the range of operation was greater for the IRF studies.

With some exceptions, numerous inverse correlations were observed between various PIC emission characterization parameters and temperature in the primary, secondary, and afterburner zones. The strong nature of these correlations was not observed for any of the full-scale tests evaluated. These negative correlations arise from parametric studies of the effect of very low temperatures (cf. Tables 3.18 and 3.19) on POHC destruction and PIC formation. The residence times and gas flow rates for these three zones, however, exhibited nearly equal numbers of both positive and negative correlations with PIC emissions. Once again, a significant correlation was observed between stack O_2 concentration and various measures of PIC emissions. This is again attributable to the three possibilities previously discussed; however, poor waste/air for mixing again appears to be the most likely effect. There were generally strong negative correlations between PIC emissions and the waste/fuel mass flow rate suggesting that the addition of fuel adversely affected PIC emissions. The observed PICs from one of the studies, chlorobenzene and 1,3-dichlorobenzene, are certainly attributable to dechlorination of 1,2,4-trichlorobenzene and not the fuel. This rather surprising finding might be a result of system overload and generally poor combustion conditions; although it is not well understood.

Very little data was available concerning various PIC surrogates (CO, TUHC, benzene) and no conclusions could be made concerning their relationship to PIC emissions.

Table 4.14
Summary of Statistical Correlation Results for Pilot Scale Hazardous Waste Incinerators

KEY:
blank = not attempted,
otherwise, # correlations / # attempts

* indicates '-' correlation coefficient
** denotes that there were '+' and '-' correlation coefficients

	TEMP PRIM °C	TEMP SEC °C	TEMP QNCH °C	TEMP APCD °C	TEMP STK °C	TEMP AB °C	TEMP KILN °C	TEMP FURN °C	TEMP BOIL °C	TEMP ECON °C	RT FURN s	RT SEC s	RT AB s	RT TOTAL s	FLOW STK dscmm	FLOW STK dscmm	FLOW AB dscmm	FLOW KILN dscmm
TOT PIC EMSS RATE (ug/min)	1/2*	1/2*				0/2	0/1						1/3*	1/2*	0/2	0/2		0/3
TOT PIC EMSS CONC (ug/dscm)	1/2*	1/2*				0/2	0/1						2/3**	1/2*	0/2	1/2*		0/3
TOT PIC EMSS CONC (10% O2)	2/2*	1/2*				1/2*	1/1*						3/3**	2/2*	0/2	1/2*		1/3
% PIC EMSS / POHC INPUT	0/2	0/2				1/2*	1/1*						1/3*	0/2	0/2	0/2		0/3
% PIC EMSS / WASTE INPUT	0/2	0/2				1/2*	0/1						1/3*	0/2	0/2	0/2		0/3
TOT ClPIC EMSS RATE (ug/min)	1/2*	1/2*												1/2*	0/2			0/3
TOT ClPIC EMSS CONC (ug/dscm)	1/2*	1/2*												2/2*	0/2			0/3
TOT ClPIC EMSS CON (10% O2)	2/2*	2/2*												2/2*	0/2			0/3
% ClPIC EMSS / ClPOHC INPUT	1/2*	1/2*												1/2*	0/2			0/3
% ClPIC EMSS / ClWASTE INPUT	1/2*	1/2*												1/2*	0/2			0/3
PIC : POHC RATIO	2/2*	1/2*				2/2**	1/2						1/3	2/2*	0/2	1/2		1/3
BZ EMSS RATE (ug/min)	0/2	1/2												1/2	1/2			0/3
BZ EMSS CONC (ug/dscm)	0/2	1/2												1/2	1/2			0/3
BZ EMSS CONC (10% O2)	1/2*	2/2**												1/2*	1/2			0/3
% BZ EMSS / POHC INPUT	0/2	1/2												1/2	1/2			0/3
% BZ EMSS / WASTE INPUT	0/2	1/2												1/2	1/2			0/3
TOL EMSS RATE (ug/min)																		
TOL EMSS CONC (ug/dscm)																		
TOL EMSS CONC (10% O2)																		
% TOL EMSS / POHC INPUT																		
% TOL EMSS / WASTE INPUT																		
CHCl3 EMSS RATE (ug/min)																		
CHCl3 EMSS CONC (ug/dscm)																		
CHCl3 EMSS CONC (10% O2)																		
% CHCl3 EMSS / POHC INPUT																		
% CHCl3 EMSS / WASTE INPUT																		
CH3Cl EMSS RATE (ug/min)	1/2*	1/2*													1/2*	0/2		
CH3Cl EMSS CONC (ug/dscm)	1/2*	1/2*													1/2*	0/2		
CH3Cl EMSS CONC (10% O2)	1/1*	1/1*													2/2*	0/2		
% CH3Cl EMSS / POHC INPUT	1/2*	1/2*													1/2*	0/2		
% CH3Cl EMSS / WASTE INPUT	1/2*	1/2*													1/2*	0/2		
CH2CL2 EMSS RATE (ug/min)																		
CH2CL2 EMSS CONC (ug/dscm)																		
CH2CL2 EMSS CONC (10% O2)																		
% CH2CL2 EMSS / POHC INPUT																		
% CH2CL2 EMSS / WASTE INPUT																		
1,3-DICLBZ EMSS RATE (ug/min)						0/2	0/1						0/3				0/2	
1,3-DICLBZ EMSS CONC (ug/dscm)						0/2	0/1						0/3				0/2	
1,3-DICLBZ EMSS CONC (10% O2)						0/1	0/1						1/3				1/1*	
% 1,3-DICLBZ EMSS / POHC INPUT						1/1*	0/1						2/2**				1/1*	
% 1,3-DICLBZ EMSS / WASTE INPUT																		
CLBZ EMSS RATE (ug/min)						0/2	0/1						2/3**				0/2	
CLBZ EMSS CONC (ug/dscm)						2/2*	0/1						1/3				1/2*	
CLBZ EMSS CONC (10% O2)						2/2*	1/1*						1/3				1/2*	
% CLBZ EMSS / POHC INPUT						1/2*	0/1						1/3				2/2**	
% CLBZ EMSS / WASTE INPUT																		
TCE EMSS RATE (ug/min)																		
TCE EMSS CONC (ug/dscm)																		
TCE EMSS CONC (10% O2)																		
% TCE EMSS / POHC INPUT																		
% TCE EMSS / WASTE INPUT																		
PCA EMSS RATE (ug/min)																		
PCA EMSS CONC (ug/dscm)																		
PCA EMSS CONC (10% O2)																		
% PCA EMSS / POHC INPUT																		
% PCA EMSS / WASTE INPUT																		
1,1,1-TCA EMSS RATE (ug/min)																		
1,1,1-TCA EMSS CONC (ug/dscm)																		
1,1,1-TCA EMSS CONC (10% O2)																		
% 1,1,1-TCA EMSS / POHC INPUT																		
% 1,1,1-TCA EMSS / WASTE INPUT																		
1,1-DCE EMSS RATE (ug/min)																		
1,1-DCE EMSS CONC (ug/dscm)																		
1,1-DCE EMSS CONC (10% O2)																		
% 1,1-DCE EMSS / POHC INPUT																		
% 1,1-DCE EMSS / WASTE INPUT																		
VC EMSS RATE (ug/min)																		
VC EMSS CONC (ug/dscm)																		
VC EMSS CONC (10% O2)																		
% VC EMSS / POHC INPUT																		
% VC EMSS / WASTE INPUT																		

Table 4.14, cont.
Summary of Statistical Correlation Results for Pilot Scale Hazardous Waste Incinerators

KEY:
blank = not attempted,
otherwise, # correlations / # attempts

* indicates '-' correlation coefficient
** denotes that there were '+' and '-' correlation coefficients

	O2 PRIM %	O2 SEC %	O2 STK dry, %	O2 AB OUT %	O2 KILN OUT %	O2 BOILER %	CO PRIM ppm	CO STK ppm	CO KILN ppm	NOx PRIM ppm	THC COLD ppm,3% O2	THC HOT ppm,3% O2	PART STK g/sec	PART STK mg/dscm	PART APCD g/dscm	APCD EFFIC %
TOT PIC EMISS RATE (ug/min)	0/2	1/2	0/2				1/3			0/3				0/2		
TOT PIC EMISS CONC (ug/dscm)	0/2	1/2	0/2				1/3			0/3				0/2		
TOT PIC EMISS CONC (10% O2)	0/2	1/2	1/2				1/3			1/3*				0/2		
% PIC EMISS / POHC INPUT	0/2	0/2	1/2				1/3			0/3				0/2		
% PIC EMISS / WASTE INPUT	0/2	0/2	0/2				1/3			0/3				0/2		
TOT CIPIC EMISS RATE (ug/min)	1/2	1/2					0/2			0/2				0/2		
TOT CIPIC EMISS CONC (ug/dscm)	0/2	1/2					0/2			0/2				0/2		
TOT CIPIC EMISS CON (10% O2)	0/2	1/2					0/2			0/2				0/2		
% CIPIC EMISS / CIPOHC INPUT	0/2	1/2					0/2			0/2				0/2		
% CIPIC EMISS / CIWASTE INPUT	0/2	1/2					0/2			0/2				0/2		
PIC : POHC RATIO	0/2	0/2	0/2				0/3			1/3*				0/2		
BZ EMISS RATE (ug/min)	1/2*	0/2					0/2			1/2*				0/2		
BZ EMISS CONC (ug/dscm)	1/2*	0/2					0/2			0/2				0/2		
BZ EMISS CONC (10% O2)	1/2*	0/2					1/2*			1/2*				0/2		
% BZ EMISS / POHC INPUT	1/2*	0/2					1/2*			0/2				0/2		
% BZ EMISS / WASTE INPUT	1/2*	0/2					1/2*			0/2				0/2		
TOL EMISS RATE (ug/min)																
TOL EMISS CONC (ug/dscm)																
TOL EMISS CONC (10% O2)																
% TOL EMISS / POHC INPUT																
% TOL EMISS / WASTE INPUT																
CHCl3 EMISS RATE (ug/min)																
CHCl3 EMISS CONC (ug/dscm)																
CHCl3 EMISS CONC (10% O2)																
% CHCl3 EMISS / POHC INPUT																
% CHCl3 EMISS / WASTE INPUT																
CH3Cl EMISS RATE (ug/min)	0/2	0/2	1/2				1/2*			0/2				1/2		
CH3Cl EMISS CONC (ug/dscm)	1/2*	0/2	1/2				0/2			0/2				0/2		
CH3Cl EMISS CONC (10% O2)	2/2**	0/2	1/2				0/2			0/2				1/2		
% CH3Cl EMISS / POHC INPUT	1/2*	0/2	1/2				0/2			0/2				0/2		
% CH3Cl EMISS / WASTE INPUT	1/2*	0/2	1/2				0/2			0/2				0/2		
CH2CL2 EMISS RATE (ug/min)																
CH2CL2 EMISS CONC (ug/dscm)																
CH2CL2 EMISS CONC (10% O2)																
% CH2CL2 EMISS / POHC INPUT																
% CH2CL2 EMISS / WASTE INPUT																
1,3-DICLBZ EMISS RATE (ug/min)	1/1			0/2			1/1			0/1						
1,3-DICLBZ EMISS CONC (ug/dscm)	0/1			0/2			1/1			0/1						
1,3-DICLBZ EMISS CONC (10% O2)	0/1			0/1			1/1			0/1						
% 1,3-DICLBZ EMISS / POHC INPUT	1/1			0/1			1/1			0/1						
% 1,3-DICLBZ EMISS / WASTE INPUT																
CLBZ EMISS RATE (ug/min)	1/1			0/2			1/1			1/1						
CLBZ EMISS CONC (ug/dscm)	0/1			0/2			0/1			1/1						
CLBZ EMISS CONC (10% O2)	1/1			1/2			0/1			1/1						
% CLBZ EMISS / POHC INPUT	0/1			1/2			0/1			0/1						
% CLBZ EMISS / WASTE INPUT																
TCE EMISS RATE (ug/min)																
TCE EMISS CONC (ug/dscm)																
TCE EMISS CONC (10% O2)																
% TCE EMISS / POHC INPUT																
% TCE EMISS / WASTE INPUT																
PCA EMISS RATE (ug/min)																
PCA EMISS CONC (ug/dscm)																
PCA EMISS CONC (10% O2)																
% PCA EMISS / POHC INPUT																
% PCA EMISS / WASTE INPUT																
1,1,1-TCA EMISS RATE (ug/min)																
1,1,1-TCA EMISS CONC (ug/dscm)																
1,1,1-TCA EMISS CONC (10% O2)																
% 1,1,1-TCA EMISS / POHC INPUT																
% 1,1,1-TCA EMISS / WASTE INPUT																
1,1-DCE EMISS RATE (ug/min)																
1,1-DCE EMISS CONC (ug/dscm)																
1,1-DCE EMISS CONC (10% O2)																
% 1,1-DCE EMISS / POHC INPUT																
% 1,1-DCE EMISS / WASTE INPUT																
VC EMISS RATE (ug/min)																
VC EMISS CONC (ug/dscm)																
VC EMISS CONC (10% O2)																
% VC EMISS / POHC INPUT																
% VC EMISS / WASTE INPUT																

Table 4.14, cont.
Summary of Statistical Correlation Results for Pilot Scale Hazardous Waste Incinerators

KEY:
blank = not attempted,
otherwise, # correlations / # attempts

* indicates ' - ' correlation coefficient
** denotes that there were ' + ' and ' - ' correlation coefficients

	Cl POHC FEED g/min	H Cl STK mg/dscm	Cl SCRBS IN mg/L	Cl SCRBS OUT mg/L	Cl OUT -vs- Cl IN SCRUB ratio	LOAD MBtu/hr	LOAD lb/hr	WASTE -vs- FUEL ratio	# POHCS	C1 TO C6 HC	BZ EMISS RATE ug/min	BZ EMISS CONC ug/dscm	BZ EMISS CONC 10% O2
TOT PIC EMISS RATE (ug/min)	0/2	2/2						1/3*			0/2	0/2	0/2
TOT PIC EMISS CONC (ug/dscm)	1/2*	0/2						1/3*			0/2	1/2	1/2
TOT PIC EMISS CONC (10% O2)	1/2*	1/2						2/3**			0/2	1/2	1/2
% PIC EMISS / POHC INPUT	0/2	0/2						1/3			1/2	1/2	1/2
% PIC EMISS / WASTE INPUT	0/2	2/2						0/3			1/2	1/2	1/2
TOT ClPIC EMISS RATE (ug/min)	1/2*	0/2						0/2			1/2	1/2	1/2
TOT ClPIC EMISS CONC (ug/dscm)	0/2	0/2						1/2			0/2	1/2	1/2
TOT ClPIC EMISS CON (10% O2)	0/2	0/2						2/2			0/2	0/2	1/2
% ClPIC EMISS / ClPOHC INPUT	1/2*	0/2						0/2			0/2	1/2	1/2
% ClPIC EMISS / ClWASTE INPUT	1/2*	0/2						0/2			0/2	1/2	1/2
PIC : POHC RATIO	0/2	0/2						2/3**			0/2	1/2	1/2
BZ EMISS RATE (ug/min)	0/2	0/2						1/2*					
BZ EMISS CONC (ug/dscm)	0/2	0/2						1/2*					
BZ EMISS CONC (10% O2)	1/2*	0/2						2/2**					
% BZ EMISS / POHC INPUT	0/2	0/2						1/2*					
% BZ EMISS / WASTE INPUT	0/2	0/2						1/2*					
TOL EMISS RATE (ug/min)													
TOL EMISS CONC (ug/dscm)													
TOL EMISS CONC (10% O2)													
% TOL EMISS / POHC INPUT													
% TOL EMISS / WASTE INPUT													
CHCl3 EMISS RATE (ug/min)													
CHCl3 EMISS CONC (ug/dscm)													
CHCl3 EMISS CONC (10% O2)													
% CHCl3 EMISS / POHC INPUT													
% CHCl3 EMISS / WASTE INPUT													
CH3Cl EMISS RATE (ug/min)	1/2	0/2						0/2			0/2	1/2	1/2
CH3Cl EMISS CONC (ug/dscm)	0/2	0/2						1/2			0/2	0/2	1/2
CH3Cl EMISS CONC (10% O2)	0/2	0/2						1/2			0/2	0/2	1/2
% CH3Cl EMISS / POHC INPUT	1/2	0/2						0/2			1/2	1/2	1/2
% CH3Cl EMISS / WASTE INPUT	1/2	0/2						0/2			1/2	1/2	1/2
CH2CL2 EMISS RATE (ug/min)													
CH2CL2 EMISS CONC (ug/dscm)													
CH2CL2 EMISS CONC (10% O2)													
% CH2CL2 EMISS / POHC INPUT													
% CH2CL2 EMISS / WASTE INPUT													
1,3-DICLBZ EMISS RATE (ug/min)								1/1*					
1,3-DICLBZ EMISS CONC (ug/dscm)								1/1*					
1,3-DICLBZ EMISS CONC (10% O2)								1/1*					
% 1,3-DICLBZ EMISS / POHC INPUT								0/1					
% 1,3-DICLBZ EMISS / WASTE INPUT													
CLBZ EMISS RATE (ug/min)								1/1*					
CLBZ EMISS CONC (ug/dscm)								1/1*					
CLBZ EMISS CONC (10% O2)								0/1					
% CLBZ EMISS / POHC INPUT								1/1					
% CLBZ EMISS / WASTE INPUT													
TCE EMISS RATE (ug/min)													
TCE EMISS CONC (ug/dscm)													
TCE EMISS CONC (10% O2)													
% TCE EMISS / POHC INPUT													
% TCE EMISS / WASTE INPUT													
PCA EMISS RATE (ug/min)													
PCA EMISS CONC (ug/dscm)													
PCA EMISS CONC (10% O2)													
% PCA EMISS / POHC INPUT													
% PCA EMISS / WASTE INPUT													
1,1,1-TCA EMISS RATE (ug/min)													
1,1,1-TCA EMISS CONC (ug/dscm)													
1,1,1-TCA EMISS CONC (10% O2)													
% 1,1,1-TCA EMISS / POHC INPUT													
% 1,1,1-TCA EMISS / WASTE INPUT													
1,1-DCE EMISS RATE (ug/min)													
1,1-DCE EMISS CONC (ug/dscm)													
1,1-DCE EMISS CONC (10% O2)													
% 1,1-DCE EMISS / POHC INPUT													
% 1,1-DCE EMISS / WASTE INPUT													
VC EMISS RATE (ug/min)													
VC EMISS CONC (ug/dscm)													
VC EMISS CONC (10% O2)													
% VC EMISS / POHC INPUT													
% VC EMISS / WASTE INPUT													

Table 4.14, cont.
Summary of Statistical Correlation Results for Pilot Scale Hazardous Waste Incinerators

KEY:
blank = not attempted,
otherwise, # correlations / # attempts

* indicates '-' correlation coefficient
** denotes that there were '+' and '-' correlation coefficients

	% BZ EMISS /POHC Inp	% BZ EMISS /WASTE Inp	TOL EMISS RATE ug/min	TOL EMISS CONC ug/dscm	TOL EMISS CONC 10% O2	% TOL EMISS /POHC Inp	% TOL EMISS /WASTE Inp	BZ + TOL EMISS RATE ug/min	BZ + TOL EMISS CONC ug/dscm	BZ + TOL EMISS CONC 10% O2	% BZ+TOL EMISS /POHC Inp	% BZ+TOL EMISS WASTE Inp
TOT PIC EMISS RATE (ug/min)	0/2	0/2										
TOT PIC EMISS CONC (ug/dscm)	1/2	1/2										
TOT PIC EMISS CONC (10% O2)	1/2	1/2										
% PIC EMISS / POHC INPUT	1/2	1/2										
% PIC EMISS / WASTE INPUT	1/2	1/2										
TOT ClPIC EMISS RATE (ug/min)	1/2	1/2										
TOT ClPIC EMISS CONC (ug/dscm)	1/2	1/2										
TOT ClPIC EMISS CONC (10% O2)	1/2**	1/2**										
% ClPIC EMISS / ClPOHC INPUT	1/2	1/2										
% ClPIC EMISS / ClWASTE INPUT	1/2	1/2										
PIC : POHC RATIO	1/2	1/2										
BZ EMISS RATE (ug/min)												
BZ EMISS CONC (ug/dscm)												
BZ EMISS CONC (10% O2)												
% BZ EMISS / POHC INPUT												
% BZ EMISS / WASTE INPUT												
TOL EMISS RATE (ug/min)												
TOL EMISS CONC (ug/dscm)												
TOL EMISS CONC (10% O2)												
% TOL EMISS / POHC INPUT												
% TOL EMISS / WASTE INPUT												
CHCl3 EMISS RATE (ug/min)												
CHCl3 EMISS CONC (ug/dscm)												
CHCl3 EMISS CONC (10% O2)												
% CHCl3 EMISS / POHC INPUT												
% CHCl3 EMISS / WASTE INPUT												
CH3Cl EMISS RATE (ug/min)	1/2	1/2										
CH3Cl EMISS CONC (ug/dscm)	0/2	0/2										
CH3Cl EMISS CONC (10% O2)	0/2	0/2										
% CH3Cl EMISS / POHC INPUT	1/2	1/2										
% CH3Cl EMISS / WASTE INPUT	1/2	1/2										
CH2CL2 EMISS RATE (ug/min)												
CH2CL2 EMISS CONC (ug/dscm)												
CH2CL2 EMISS CONC (10% O2)												
% CH2CL2 EMISS / POHC INPUT												
% CH2CL2 EMISS / WASTE INPUT												
1,3-DICLBZ EMISS RATE (ug/min)												
1,3-DICLBZ EMISS CONC (ug/dscm)												
1,3-DICLBZ EMISS CONC (10% O2)												
% 1,3-DICLBZ EMISS / POHC INPUT												
% 1,3-DICLBZ EMISS / WASTE INPUT												
CLBZ EMISS RATE (ug/min)												
CLBZ EMISS CONC (ug/dscm)												
CLBZ EMISS CONC (10% O2)												
% CLBZ EMISS / POHC INPUT												
% CLBZ EMISS / WASTE INPUT												
TCE EMISS RATE (ug/min)												
TCE EMISS CONC (ug/dscm)												
TCE EMISS CONC (10% O2)												
% TCE EMISS / POHC INPUT												
% TCE EMISS / WASTE INPUT												
PCA EMISS RATE (ug/min)												
PCA EMISS CONC (ug/dscm)												
PCA EMISS CONC (10% O2)												
% PCA EMISS / POHC INPUT												
% PCA EMISS / WASTE INPUT												
1,1,1-TCA EMISS RATE (ug/min)												
1,1,1-TCA EMISS CONC (ug/dscm)												
1,1,1-TCA EMISS CONC (10% O2)												
% 1,1,1-TCA EMISS / POHC INPUT												
% 1,1,1-TCA EMISS / WASTE INPUT												
1,1-DCE EMISS RATE (ug/min)												
1,1-DCE EMISS CONC (ug/dscm)												
1,1-DCE EMISS CONC (10% O2)												
% 1,1-DCE EMISS / POHC INPUT												
% 1,1-DCE EMISS / WASTE INPUT												
VC EMISS RATE (ug/min)												
VC EMISS CONC (ug/dscm)												
VC EMISS CONC (10% O2)												
% VC EMISS / POHC INPUT												
% VC EMISS / WASTE INPUT												

Full-Scale Boilers

Sufficient PIC data were obtained for only 3 facilities with the summary data presented in Table 4.15. The results for each individual study are presented in Tables 4.9-4.11.

There were not any consistent statistically significant correlations between any of the available temperature or residence time data and any measures of PIC emissions. Correlations were observed between the stack O_2 concentration and the boiler O_2 concentration and various measures of PIC emissions; however, both positive and negative correlations were observed. CO did not show rank/order correlations with any measures of PIC emissions except for toluene, although it must be noted that the data base was generally inadequate to draw firm conclusions concerning the occurrences (or lack of occurrence) of even rank/order type correlations. Some correlations were observed between waste heat load (MBtu/hr), again indicating that overload may contribute to PIC emissions, although the correlations were not very strong.

The strongest correlations were observed between various measures of benzene and toluene emissions and various measures of chlorinated PIC emissions, although data was very limited.

Full-Scale Co-fired Kilns

Very limited data were available for co-fired kilns as only one study had sufficient data to include in the statistical database (see Table 4.12).

The most notable relationship was the negative correlation between the stack O_2 concentration and various measures of PIC emissions. This trend was opposite that observed in the previous studies and suggests that the air feed rate, not waste/air mixing was the limiting factor in co-fired kilns. This is not surprising since most kilns operate under lower excess air conditions than incinerators and even boilers. This oxygen-depleted operation is not always obvious from process measurement data of the O_2 concentration due to air leakage at the kiln seals.

Table 4.15
Summary of Statistical Correlation Results for Boilers Cofired with Hazardous Waste

KEY:
blank = not attempted,
otherwise, # correlations / # attempts

* indicates '-' correlation coefficient
** denotes that there were '+' and '-' correlation coefficients

	TEMP PRIM °C	TEMP SEC °C	TEMP QNCH °C	TEMP APCD °C	TEMP STK °C	TEMP AB °C	TEMP KILN °C	TEMP FURN °C	TEMP BOIL °C	TEMP ECON °C	RT FURN s	RT SEC s	RT AB s	RT TOTAL s	FLOW STK dscmm	FLOW STK dscmm	FLOW AB dscmm
TOT PIC EMISS RATE (ug/min)								0/2	0/1	0/1	1/1*					2/3	
TOT PIC EMISS CONC (ug/dscm)								1/2	0/1	0/1	0/1					1/2	
TOT PIC EMISS CONC (10% O2)								1/2	0/1	0/1	0/1					1/3	
% PIC EMISS / POHC INPUT								1/2	0/1	1/1	1/1*					1/2	
% PIC EMISS / WASTE INPUT								0/2	0/1	0/1	0/1					1/2	
TOT ClPIC EMISS RATE (ug/min)								0/2	0/1	0/1	0/1					2/3	
TOT ClPIC EMISS CONC (ug/dscm)								0/2	0/1	0/1	0/1					1/3	
TOT ClPIC EMISS CON (10% O2)								0/2	0/1	0/1	0/1					1/3	
% ClPIC EMISS / ClPOHC INPUT								0/2	0/1	0/1	0/1					0/2	
% ClPIC EMISS / ClWASTE INPUT								0/2	0/1	0/1	0/1					0/2	
PIC : POHC RATIO								1/2	0/1	0/1	0/1					1/2	
BZ EMISS RATE (ug/min)								0/2	0/1	0/1	1/1*					1/2	
BZ EMISS CONC (ug/dscm)								0/2	0/1	0/1	1/1*					1/2	
BZ EMISS CONC (10% O2)								0/2	0/1	0/1	0/1					1/2	
% BZ EMISS / POHC INPUT								0/2	0/1	0/1	1/1*					2/2	
% BZ EMISS / WASTE INPUT								0/2	0/1	0/1	0/1					1/2	
TOL EMISS RATE (ug/min)								0/2	0/1	0/1	0/1					0/3	
TOL EMISS CONC (ug/dscm)								0/2	0/1	0/1	0/1					0/3	
TOL EMISS CONC (10% O2)								0/2	0/1	0/1	0/1					0/3	
% TOL EMISS / POHC INPUT								0/2	0/1	0/1	0/1					0/3	
% TOL EMISS / WASTE INPUT								0/2	0/1	0/1	0/1					0/3	
CHCl3 EMISS RATE (ug/min)								0/1	0/1	0/1						0/1	
CHCl3 EMISS CONC (ug/dscm)								0/1	0/1	0/1						0/1	
CHCl3 EMISS CONC (10% O2)								0/1	0/1	0/1						0/1	
% CHCl3 EMISS / POHC INPUT								0/1	0/1	0/1						0/1	
% CHCl3 EMISS / WASTE INPUT								0/1	0/1	0/1						0/1	
CH3Cl EMISS RATE (ug/min)																	
CH3Cl EMISS CONC (ug/dscm)																	
CH3Cl EMISS CONC (10% O2)																	
% CH3Cl EMISS / POHC INPUT																	
% CH3Cl EMISS / WASTE INPUT																	
CH2CL2 EMISS RATE (ug/min)								0/1			0/1					0/1	
CH2CL2 EMISS CONC (ug/dscm)								0/1			0/1					0/1	
CH2CL2 EMISS CONC (10% O2)								0/1			0/1					0/1	
% CH2CL2 EMISS / POHC INPUT								0/1			0/1					0/1	
% CH2CL2 EMISS / WASTE INPUT								0/1			0/1					0/1	
1,3-DICLBZ EMISS RATE (ug/min)																	
1,3-DICLBZ EMISS CONC (ug/dscm)																	
1,3-DICLBZ EMISS CONC (10% O2)																	
% 1,3-DICLBZ EMISS / POHC INPUT																	
% 1,3-DICLBZ EMISS / WASTE INPUT																	
CLBZ EMISS RATE (ug/min)																	
CLBZ EMISS CONC (ug/dscm)																	
CLBZ EMISS CONC (10% O2)																	
% CLBZ EMISS / POHC INPUT																	
% CLBZ EMISS / WASTE INPUT																	
TCE EMISS RATE (ug/min)																	
TCE EMISS CONC (ug/dscm)																	
TCE EMISS CONC (10% O2)																	
% TCE EMISS / POHC INPUT																	
% TCE EMISS / WASTE INPUT																	
PCA EMISS RATE (ug/min)								0/1	0/1	0/1						0/1	
PCA EMISS CONC (ug/dscm)								0/1	0/1	0/1						0/1	
PCA EMISS CONC (10% O2)								0/1	0/1	0/1						0/1	
% PCA EMISS / POHC INPUT								0/1	0/1	0/1						0/1	
% PCA EMISS / WASTE INPUT								0/1	0/1	0/1						0/1	
1,1,1-TCA EMISS RATE (ug/min)																	
1,1,1-TCA EMISS CONC (ug/dscm)																	
1,1,1-TCA EMISS CONC (10% O2)																	
% 1,1,1-TCA EMISS / POHC INPUT																	
% 1,1,1-TCA EMISS / WASTE INPUT																	
1,1-DCE EMISS RATE (ug/min)								0/1								0/1	
1,1-DCE EMISS CONC (ug/dscm)								0/1								0/1	
1,1-DCE EMISS CONC (10% O2)								0/1								0/1	
% 1,1-DCE EMISS / POHC INPUT								0/1								0/1	
% 1,1-DCE EMISS / WASTE INPUT								0/1								0/1	
VC EMISS RATE (ug/min)																	
VC EMISS CONC (ug/dscm)																	
VC EMISS CONC (10% O2)																	
% VC EMISS / POHC INPUT																	
% VC EMISS / WASTE INPUT																	

Table 4.15, cont.
Summary of Statistical Correlation Results for Boilers Cofired with Hazardous Waste

KEY:
blank = not attempted,
otherwise, # correlations / # attempts

* indicates '-' correlation coefficient
** denotes that there were '+' and '-' correlation coefficients

	FLOW KILN dscmm	O2 PRIM %	O2 SEC %	O2 STK dry,%	O2 AB OUT %	O2 KILN OUT %	O2 BOILER %	CO PRIM ppm	CO STK ppm	CO KILN ppm	NOx PRIM ppm	THC COLD ppm,3% O2	THC HOT ppm,3% O2	PART STK g/sec	PART STK mg/dscm	PART APCD gr/dscm	APCD EFFIC %
TOT PIC EMISS RATE (ug/min)				1/3*			1/2*		0/3								
TOT PIC EMISS CONC (ug/dscm)				0/3			1/2*		0/3								
TOT PIC EMISS CONC (10% O2)				0/3			1/2*		0/3								
% PIC EMISS / POHC INPUT				0/2			0/2		0/2					0/2			
% PIC EMISS / WASTE INPUT				0/2			1/2*		0/2					0/2			
TOT ClPIC EMISS RATE (ug/min)				0/3			1/2*		0/2								
TOT ClPIC EMISS CONC (ug/dscm)				0/3			0/2		0/2								
TOT ClPIC EMISS CON (10% O2)				0/3			0/2		0/2								
% ClPIC EMISS / ClPOHC INPUT				0/2			0/2		0/2		0/2			0/2			
% ClPIC EMISS / ClWASTE INPUT				0/2			0/2		0/2		0/2			0/2			
PIC : POHC RATIO				0/2			1/1*		0/1		0/1			0/1			
BZ EMISS RATE (ug/min)				2/2**			1/2		0/2		1/2			1/2			
BZ EMISS CONC (ug/dscm)				2/2**			1/2		0/2		1/2			1/2			
BZ EMISS CONC (10% O2)				2/2**			1/2		0/2		0/2			1/2			
% BZ EMISS / POHC INPUT				2/2**			1/2		0/2		1/2			1/2			
% BZ EMISS / WASTE INPUT				2/2**			1/2		0/2		0/2			1/2			
TOL EMISS RATE (ug/min)				0/3			0/2		2/2**		0/3			0/3			
TOL EMISS CONC (ug/dscm)				0/3			1/2		1/2*		0/3			0/3			
TOL EMISS CONC (10% O2)				0/3			1/2		1/2*		0/3			0/3			
% TOL EMISS / POHC INPUT				1/3			1/2		0/2		0/3			0/3			
% TOL EMISS / WASTE INPUT				0/3			0/2		1/2*		0/3			0/3			
CHCl3 EMISS RATE (ug/min)				0/1			0/1		0/1		0/1			0/1			
CHCl3 EMISS CONC (ug/dscm)				0/1			0/1		0/1		0/1			0/1			
CHCl3 EMISS CONC (10% O2)				0/1			0/1		0/1		0/1			0/1			
% CHCl3 EMISS / POHC INPUT				0/1			0/1		0/1		0/1			0/1			
% CHCl3 EMISS / WASTE INPUT				0/1			0/1		0/1		0/1			0/1			
CH3Cl EMISS RATE (ug/min)																	
CH3Cl EMISS CONC (ug/dscm)																	
CH3Cl EMISS CONC (10% O2)																	
% CH3Cl EMISS / POHC INPUT																	
% CH3Cl EMISS / WASTE INPUT																	
CH2CL2 EMISS RATE (ug/min)				0/1			1/1*		0/1		0/1			0/1			
CH2CL2 EMISS CONC (ug/dscm)				0/1			1/1*		0/1		0/1			0/1			
CH2CL2 EMISS CONC (10% O2)				0/1			1/1*		0/1		0/1			0/1			
% CH2CL2 EMISS / POHC INPUT				0/1			0/1		0/1		0/1			0/1			
% CH2CL2 EMISS / WASTE INPUT				0/1			0/1		0/1		0/1			0/1			
1,3-DICLBZ EMISS RATE (ug/min)																	
1,3-DICLBZ EMISS CONC (ug/dscm)																	
1,3-DICLBZ EMISS CONC (10% O2)																	
% 1,3-DICLBZ EMISS / POHC INPUT																	
% 1,3-DICLBZ EMISS / WASTE INPUT																	
CLBZ EMISS RATE (ug/min)																	
CLBZ EMISS CONC (ug/dscm)																	
CLBZ EMISS CONC (10% O2)																	
% CLBZ EMISS / POHC INPUT																	
% CLBZ EMISS / WASTE INPUT																	
TCE EMISS RATE (ug/min)																	
TCE EMISS CONC (ug/dscm)																	
TCE EMISS CONC (10% O2)																	
% TCE EMISS / POHC INPUT																	
% TCE EMISS / WASTE INPUT																	
PCA EMISS RATE (ug/min)				0/1			0/1		1/1*		0/1			0/1			
PCA EMISS CONC (ug/dscm)				0/1			0/1		1/1*		0/1			0/1			
PCA EMISS CONC (10% O2)				0/1			0/1		0/1		0/1			0/1			
% PCA EMISS / POHC INPUT				0/1			1/1*		0/1		0/1			0/1			
% PCA EMISS / WASTE INPUT				0/1			1/1*		0/1		0/1			0/1			
1,1,1-TCA EMISS RATE (ug/min)																	
1,1,1-TCA EMISS CONC (ug/dscm)																	
1,1,1-TCA EMISS CONC (10% O2)																	
% 1,1,1-TCA EMISS / POHC INPUT																	
% 1,1,1-TCA EMISS / WASTE INPUT																	
1,1-DCE EMISS RATE (ug/min)				0/1			1/1*		0/1		0/1			0/1			
1,1-DCE EMISS CONC (ug/dscm)				0/1			0/1		0/1		0/1			0/1			
1,1-DCE EMISS CONC (10% O2)				0/1			0/1		0/1		0/1			0/1			
% 1,1-DCE EMISS / POHC INPUT				0/1			0/1		0/1		0/1			0/1			
% 1,1-DCE EMISS / WASTE INPUT				0/1			0/1		0/1		0/1			0/1			
VC EMISS RATE (ug/min)																	
VC EMISS CONC (ug/dscm)																	
VC EMISS CONC (10% O2)																	
% VC EMISS / POHC INPUT																	
% VC EMISS / WASTE INPUT																	

Table 4.15, cont.
Summary of Statistical Correlation Results for Boilers Cofired with Hazardous Waste

KEY:
blank = not attempted,
otherwise, # correlations / # attempts

* indicates '-' correlation coefficient
** denotes that there were '+' and '-' correlation coefficients

	ClPOHC FEED g/min	HCl STK mg/dscm	Cl SCRBS IN mg/L	Cl SCRBS OUT mg/L	Cl OUT -vs- Cl IN SCRUBS ratio	LOAD MBtu/hr	LOAD lb/hr	WASTE -vs- FUEL ratio	# POHCS	C1 TO C6 HC	BZ EMISS RATE ug/min	BZ EMISS CONC ug/dscm	BZ EMISS CONC 10% O2
TOT PIC EMISS RATE (ug/min)						1/3		2/3*	1/2*	0/2	0/3	1/3	1/3
TOT PIC EMISS CONC (ug/dscm)						0/3		2/3*	0/2	0/2	0/3	0/3	0/3
TOT PIC EMISS CONC (10% O2)						0/3		2/3*	0/2	0/2	0/3	0/3	0/3
% PIC EMISS / POHC INPUT						1/2		1/2*	1/2*	0/2	0/2	0/2	0/2
% PIC EMISS / WASTE INPUT	0/2					1/2		2/2*	0/2	0/2	0/2	0/2	0/2
TOT ClPIC EMISS RATE (ug/min)						1/3		2/3*	0/2	0/2	0/3	0/3	0/3
TOT ClPIC EMISS CONC (ug/dscm)						0/3		1/3*	0/2	1/2	1/3	1/3	1/3
TOT ClPIC EMISS CON (10% O2)						0/3		1/3*	0/2	1/2	1/3	1/3	1/3
% ClPIC EMISS / ClPOHC INPUT	0/2	0/2				0/2		0/2	0/2	1/2	0/2	0/2	1/2*
% ClPIC EMISS / ClWASTE INPUT	0/2	0/2				0/2		0/2	0/2	1/2	0/2	0/2	1/2*
PIC : POHC RATIO	0/2	0/2				1/2		0/2	0/2	1/2	0/1	0/1	0/1
BZ EMISS RATE (ug/min)	1/2	1/2				1/2		0/2	2/2**	0/2			
BZ EMISS CONC (ug/dscm)	1/2	1/2				1/2		0/2	1/2*	1/2*			
BZ EMISS CONC (10% O2)	1/2	1/2				1/2		0/2	0/2	1/2*			
% BZ EMISS / POHC INPUT	1/2	1/2				1/2		0/2	2/2**	1/2*			
% BZ EMISS / WASTE INPUT	1/2	1/2				1/2		0/2	0/2	1/2*			
TOL EMISS RATE (ug/min)	0/3	0/3				0/3		1/3*	0/2	1/2			
TOL EMISS CONC (ug/dscm)	0/3	0/3				0/3		1/3*	0/2	0/2			
TOL EMISS CONC (10% O2)	0/3	0/3				0/3		1/3*	0/2	0/2			
% TOL EMISS / POHC INPUT	0/3	0/3				0/3		0/3	0/3	0/3			
% TOL EMISS / WASTE INPUT	0/3	0/3				0/3		1/3*	0/3	0/3			
CHCl3 EMISS RATE (ug/min)	0/1	0/1				0/1		0/1	0/1	0/1	1/1	1/1	1/1
CHCl3 EMISS CONC (ug/dscm)	0/1	0/1				0/1		0/1	0/1	0/1	1/1	1/1	1/1
CHCl3 EMISS CONC (10% O2)	0/1	0/1				0/1		0/1	0/1	0/1	1/1	1/1	1/1
% CHCl3 EMISS / POHC INPUT	0/1	1/1				0/1		0/1	1/1	0/1	1/1	1/1	1/1
% CHCl3 EMISS / WASTE INPUT	0/1	1/1				0/1		0/1	1/1	0/1	1/1	1/1	1/1
CH3Cl EMISS RATE (ug/min)													
CH3Cl EMISS CONC (ug/dscm)													
CH3Cl EMISS CONC (10% O2)													
% CH3Cl EMISS / POHC INPUT													
% CH3Cl EMISS / WASTE INPUT													
CH2CL2 EMISS RATE (ug/min)	0/1	1/1				1/1		1/1*	0/1	0/1	0/1	0/1	0/1
CH2CL2 EMISS CONC (ug/dscm)	0/1	0/1				0/1		1/1*	0/1	0/1	0/1	0/1	0/1
CH2CL2 EMISS CONC (10% O2)	0/1	0/1				0/1		1/1*	0/1	0/1	0/1	0/1	0/1
% CH2CL2 EMISS / POHC INPUT	0/1	0/1				0/1		0/1	0/1	1/1	0/1	0/1	1/1*
% CH2CL2 EMISS / WASTE INPUT	0/1	0/1				0/1		0/1	0/1	1/1	0/1	0/1	1/1*
1,3-DICLBZ EMISS RATE (ug/min)													
1,3-DICLBZ EMISS CONC (ug/dscm)													
1,3-DICLBZ EMISS CONC (10% O2)													
% 1,3-DICLBZ EMISS / POHC INPUT													
% 1,3-DICLBZ EMISS / WASTE INPUT													
CLBZ EMISS RATE (ug/min)													
CLBZ EMISS CONC (ug/dscm)													
CLBZ EMISS CONC (10% O2)													
% CLBZ EMISS / POHC INPUT													
% CLBZ EMISS / WASTE INPUT													
TCE EMISS RATE (ug/min)													
TCE EMISS CONC (ug/dscm)													
TCE EMISS CONC (10% O2)													
% TCE EMISS / POHC INPUT													
% TCE EMISS / WASTE INPUT													
PCA EMISS RATE (ug/min)	0/1	0/1				0/1		1/1*	0/1	0/1	1/1	1/1	1/1
PCA EMISS CONC (ug/dscm)	0/1	0/1				0/1		1/1*	0/1	0/1	1/1	1/1	1/1
PCA EMISS CONC (10% O2)	0/1	0/1				0/1		1/1*	0/1	1/1*	1/1	1/1	1/1
% PCA EMISS / POHC INPUT	0/1	0/1				0/1		1/1*	0/1	0/1	0/1	0/1	0/1
% PCA EMISS / WASTE INPUT	0/1	0/1				0/1		1/1*	0/1	0/1	0/1	0/1	0/1
1,1,1-TCA EMISS RATE (ug/min)													
1,1,1-TCA EMISS CONC (ug/dscm)													
1,1,1-TCA EMISS CONC (10% O2)													
% 1,1,1-TCA EMISS / POHC INPUT													
% 1,1,1-TCA EMISS / WASTE INPUT													
1,1-DCE EMISS RATE (ug/min)	0/1	0/1				0/1		3/1	0/1	0/1	0/1	0/1	0/1
1,1-DCE EMISS CONC (ug/dscm)	0/1	0/1				0/1		1/1*	0/1	0/1	0/1	0/1	0/1
1,1-DCE EMISS CONC (10% O2)	0/1	0/1				0/1		1/1*	0/1	0/1	0/1	0/1	0/1
% 1,1-DCE EMISS / POHC INPUT	0/1	0/1				0/1		1/1*	0/1	1/1	0/1	0/1	0/1
% 1,1-DCE EMISS / WASTE INPUT	0/1	0/1				0/1		0/1	0/1	1/1	0/1	0/1	0/1
VC EMISS RATE (ug/min)													
VC EMISS CONC (ug/dscm)													
VC EMISS CONC (10% O2)													
% VC EMISS / POHC INPUT													
% VC EMISS / WASTE INPUT													

Table 4.15, cont.
Summary of Statistical Correlation Results for Boilers Cofired with Hazardous Waste

KEY:
blank = not attempted,
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* indicates '-' correlation coefficient
** denotes that there were '+' and '-' correlation coefficients

	% BZ EMISS /POHC inp	% BZ EMISS /WASTE inp	TOL EMISS RATE ug/min	TOL EMISS CONC ug/dscm	TOL EMISS CONC 10% O2	% TOL EMISS /POHC inp	% TOL EMISS /WASTE inp	BZ + TOL EMISS RATE ug/min	BZ + TOL EMISS CONC ug/dscm	BZ + TOL EMISS CONC 10% O2	% BZ+TOL EMISS /POHC inp	% BZ+TOL EMISS /WASTE inp
TOT PIC EMISS RATE (ug/min)	1/3	1/3	0/3	0/3	0/3	0/3	0/3	0/3	0/3	0/3	0/3	1/3
TOT PIC EMISS CONC (ug/dscm)	0/3	0/3	0/3	0/3	0/3	0/3	0/3	0/3	0/3	0/3	0/3	1/3
TOT PIC EMISS CONC (10% O2)	0/3	0/3	0/3	0/3	0/3	0/3	0/3	0/3	0/3	0/3	0/3	1/3
% PIC EMISS / POHC INPUT	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	1/2*	0/2	0/2
% PIC EMISS / WASTE INPUT	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	0/2	1/2*	0/2	0/2
TOT ClPIC EMISS RATE (ug/min)	0/3	0/3	0/3	0/3	0/3	0/3	0/3	0/3	0/3	1/3	0/3	0/3
TOT ClPIC EMISS CONC (ug/dscm)	1/3	1/3	0/3	0/3	0/3	0/3	0/3	1/3*	1/3*	1/3	0/3	1/3
TOT ClPIC EMISS CON (10% O2)	1/3	1/3	0/3	0/3	0/3	0/3	0/3	1/3*	1/3*	1/3	0/3	1/3
% ClPIC EMISS / ClPOHC INPUT	0/2	1/2*	1/2*	0/2	0/2	0/2	1/2*	1/2*	1/2*	1/2*	1/2*	1/2*
% ClPIC EMISS / ClWASTE INPUT	0/2	1/2*	1/2*	0/2	0/2	0/2	1/2*	1/2*	1/2*	1/2*	1/2*	1/2*
PIC : POHC RATIO	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1			
BZ EMISS RATE (ug/min)												
BZ EMISS CONC (ug/dscm)												
BZ EMISS CONC (10% O2)												
% BZ EMISS / POHC INPUT												
% BZ EMISS / WASTE INPUT												
TOL EMISS RATE (ug/min)												
TOL EMISS CONC (ug/dscm)												
TOL EMISS CONC (10% O2)												
% TOL EMISS / POHC INPUT												
% TOL EMISS / WASTE INPUT	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1			
CHCl3 EMISS RATE (ug/min)	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1
CHCl3 EMISS CONC (ug/dscm)	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1
CHCl3 EMISS CONC (10% O2)	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1
% CHCl3 EMISS / POHC INPUT	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1
% CHCl3 EMISS / WASTE INPUT	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1
CH3Cl EMISS RATE (ug/min)												
CH3Cl EMISS CONC (ug/dscm)												
CH3Cl EMISS CONC (10% O2)												
% CH3Cl EMISS / POHC INPUT												
% CH3Cl EMISS / WASTE INPUT												
CH2CL2 EMISS RATE (ug/min)	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	1/1*	0/1	0/1
CH2CL2 EMISS CONC (ug/dscm)	0/1	0/1	0/1	0/1	0/1	0/1	1/1*	0/1	0/1	1/1*	0/1	1/1*
CH2CL2 EMISS CONC (10% O2)	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	1/1*	1/1*	0/1	0/1
% CH2CL2 EMISS / POHC INPUT	0/1	1/1*	0/1	0/1	0/1	0/1	0/1	1/1*	1/1*	1/1*	1/1*	0/1
% CH2CL2 EMISS / WASTE INPUT	0/1	1/1*	0/1	0/1	0/1	0/1	0/1	1/1*	1/1*	1/1*	1/1*	0/1
1,3-DICLBZ EMISS RATE (ug/min)												
1,3-DICLBZ EMISS CONC (ug/dscm)												
1,3-DICLBZ EMISS CONC (10% O2)												
% 1,3-DICLBZ EMISS / POHC INPUT												
% 1,3-DICLBZ EMISS / WASTE INPUT												
CLBZ EMISS RATE (ug/min)												
CLBZ EMISS CONC (ug/dscm)												
CLBZ EMISS CONC (10% O2)												
% CLBZ EMISS / POHC INPUT												
% CLBZ EMISS / WASTE INPUT												
TCE EMISS RATE (ug/min)												
TCE EMISS CONC (ug/dscm)												
TCE EMISS CONC (10% O2)												
% TCE EMISS / POHC INPUT												
% TCE EMISS / WASTE INPUT												
PCA EMISS RATE (ug/min)	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1
PCA EMISS CONC (ug/dscm)	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1
PCA EMISS CONC (10% O2)	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1
% PCA EMISS / POHC INPUT	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1
% PCA EMISS / WASTE INPUT	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1
1,1,1-TCA EMISS RATE (ug/min)												
1,1,1-TCA EMISS CONC (ug/dscm)												
1,1,1-TCA EMISS CONC (10% O2)												
% 1,1,1-TCA EMISS / POHC INPUT												
% 1,1,1-TCA EMISS / WASTE INPUT												
1,1-DCE EMISS RATE (ug/min)	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1
1,1-DCE EMISS CONC (ug/dscm)	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1
1,1-DCE EMISS CONC (10% O2)	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1
% 1,1-DCE EMISS / POHC INPUT	0/1	0/1	0/1	0/1	0/1	0/1	0/1	1/1*	1/1*	1/1*	0/1	0/1
% 1,1-DCE EMISS / WASTE INPUT	0/1	0/1	0/1	0/1	0/1	0/1	0/1	1/1*	1/1*	1/1*	0/1	0/1
VC EMISS RATE (ug/min)												
VC EMISS CONC (ug/dscm)												
VC EMISS CONC (10% O2)												
% VC EMISS / POHC INPUT												
% VC EMISS / WASTE INPUT												

There were strong positive correlations between toluene concentrations and various measures of PIC formation and a strong negative correlation for benzene. The negative correlation for benzene was highly unusual but might be due to its low concentration versus toluene (which is also unusual). Once again, the trend that normalized variables such as concentration, concentration corrected 10% O_2 and concentrations normalized to POHC input gave better correlations than unnormalized variables (e.g., emission rate) was observed.

General Observations and Conclusions

We have attempted to analyze the results of full- and pilot-scale emission data in a quantitative and qualitative manner. We have conducted an in-depth review of the available data from a scientific viewpoint, incorporating chemical kinetic, thermodynamic, and engineering principles. We must generally conclude that the available field data on PICs is insufficient in volume and quality to make firm conclusions; however, some trends are noticeable, certain correlations appear stronger than others, and some results seem to concur with scientific theory. These items are enumerated in the following paragraphs.

1. The most frequently proposed regulatory surrogates for PIC emissions (CO, hot TUHC, cold TUHC) exhibited occasional correlations with various measures of PIC emissions. Stack concentrations of benzene and toluene exhibited a larger number of correlations with total measured PICs, chlorinated PICs, and some individual PICs. That any correlations were observed at all for those surrogates is encouraging, in light of limited range of conditions tested and the limited number of reliable data points that were available.

2. Of the various design and operational parameters included in our statistical analysis, the stack O_2 concentration and the waste heat load exhibited the strongest correlations with PIC emissions. Both seem to be related to mixing of waste/fuel and air in zones 2 and 3 of the facility. The stack O_2 concentration appeared to

be a measure of "mixing and combustion efficiency" as the O_2 concentration generally exhibited a positive correlation with PIC emissions. This relationship was observed for incinerators and boilers but not kilns which operate near stoichiometric air.

3. Unfortunately, sampling for PIC emissions was limited to "target" lists and major emissions. Thus, the majority of the PICs that could have been emitted from the facility were not analyzed. Those omitted generally included the very low molecular weight and very high molecular weight species. Since both classes are associated with particulate matter (through sorption for low molecular weight species and condensation and molecular growth for high molecular weight species), upset conditions where sooting is more probable could actually result in less measured PIC emissions. However, contaminated particulate which is inhaled or ingested may release these materials to the body.

4. With the caveat concerning the completeness of PIC data, results indicated that chlorinated PICs and total PICs measure as less than 0.01% of the POHC feed for all incinerator studies except the Dow Chemical incinerator study, which emitted PICs at 1-3 orders of magnitude greater rate than residual POHCs. Boilers emitted chlorinated PICs and total PICs at a rate >0.01% of the POHC feed in 50-60% of the tests conducted. Kiln data was insufficient to make any conclusions. There was a strong tendency to record more PIC emissions when more compounds were sampled, again suggesting the incompleteness of the data. This selective sampling and analysis data strongly biases PIC frequency and concentration summary analyses.

5. The test results on boilers indicated that the fuel did contribute to PIC emissions but could not account for the greater emissions of PICs from boilers versus incinerators. It is interesting to note that a hydrocarbon fuel would be expected to produce compounds more easily identifiable in a standard GC/MS library than the exotic PICs produced from poor combustion of toxic halocarbons and other

heteroatom containing compounds. The limited data suggested that physical and chemical interactions of the fuel and waste were responsible for much of the PIC emissions.

6. PIC emissions were always several orders of magnitude higher than predictions based on PIC formation/destruction rates calculated from kinetic theory and nominal incineration conditions. This suggests that temporal or spatial excursions from these nominal conditions are occurring that are responsible for PIC emissions. This hypothesis is the same as has been previously proposed to be responsible for emissions of residual POHCs. Low temperatures due to quenching or nonuniformities, residence time short circuits due to non-plug flow and/or unswept recesses and locally high waste/O_2 ratios due to poor mixing or overloading are implicated as failure modes. These failure modes may be transient due to phenomena such as flame-out or flash vaporization of overloads.

7. Based on limited data, simple halogenated methanes and aromatic species were the most frequently observed and highest yield PICs. Chlorinated ethenes and ethanes were the next most prevalent group. The observation that simple halomethanes, haloethanes, and aromatics were observed as major PICs is notable in that they are expected to be formed late in the thermal destruction process. The aromatic species are a result of complex molecular growth in zones 2 and 3 and likely formed at the end of these zones. The fragile highly halogenated methanes and ethanes are likely to be formed by radical association reactions in zone 4 where once formed, they are not subject to extreme conditions of thermal degradation.

SECTION 5

IMPLICATIONS FOR PIC CONTROL
-SUGGESTED AREAS FOR FURTHER RESEARCH-

A review of laboratory-scale experiments and a rank-order statistical analysis of pilot- and full-scale test burns suggests that the majority of PIC emissions in full-scale thermal destruction facilities are closely related to reaction conditions occurring in the post-flame and cool zones. This review has resulted in the identification of several concepts that hold promise for minimizing PIC emissions. Many of these concepts are already well-known in the combustion community, while others have been previously proposed but are not as well documented. However, it appears that sufficient information has now been gathered such that research on these concepts can be conducted on a firmer scientific basis. In any case, it would appear there is something to be gained by re-emphasis and support of the following PIC minimization concepts:

1. enhanced waste/air micro-mixing
2. plug flow conditions in post-flame zones,
3. positive temperature gradient in high-temperature zones,
4. slow quenching in cool zones,
5. low concentration of direct, chlorinated PIC precursors,
6. low Cl:H ratio in the waste (or waste/fuel mixture),
7. waste homogenization to remove high chlorine pockets,
8. comprehensive emission modeling,
9. trial burn testing for key PICs,
10. continuous monitoring of PICs.

These recommendations for PIC control can be conveniently grouped into design, operation, and regulatory implications. Each of these recommendations is briefly reviewed in the following paragraphs.

Design Implications

Residence time, temperature, and waste/oxygen mixing are often termed key combustion variables in promoting high conversion efficiencies of waste to thermodynamic end-products. As PIC formation is a direct consequence of the degree of waste combustion, the first three PIC control implications are based on optimization of these 3 parameters.

1. Enhanced waste-air mixing at the molecular level in flame and post-flame zones has been frequently identified as a PIC minimization strategy and is well known within the engineering community as good combustion practice. Recently completed research studies have re-emphasized their importance to incineration. The positive correlations between stack O_2 and waste heat load with PICs observed in some of the field studies further re-emphasizes this point. This is clearly an important area of on-going research which deserves further consideration.

2. Plug flow conditions in the post-flame zones may mitigate PIC emissions by minimizing short residence time pathways. Figure 5.1 depicts two hypothetical residence time distributions. The Type I distribution is characteristic of idealized plug flow while Type II is the broader distribution expected in conventional large-scale systems. Deviation from plug flow necessarily means a greater fraction of the molecules experience residence times shorter and longer than the mean. While longer times only fractionally increase an already large destruction efficiency, shorter residence times can severely increase PIC emissions. Kinetically, there is usually a critical residence time or breakthrough time, t_b, for which shorter times result in severely limited POHC and PIC destruction. Although this effect is generally well documented, it is not frequently addressed in incinerator design. At the very least, the magnitude of this effect should be more thoroughly evaluated.

3. A positive temperature gradient in the high-temperature zones may serve to minimize the emission of PICs. Although this practice is used in starved air systems, it is intended for optimizing the bed temperature, not PIC destruction. A few calculations were performed for the simplified kinetic scheme:

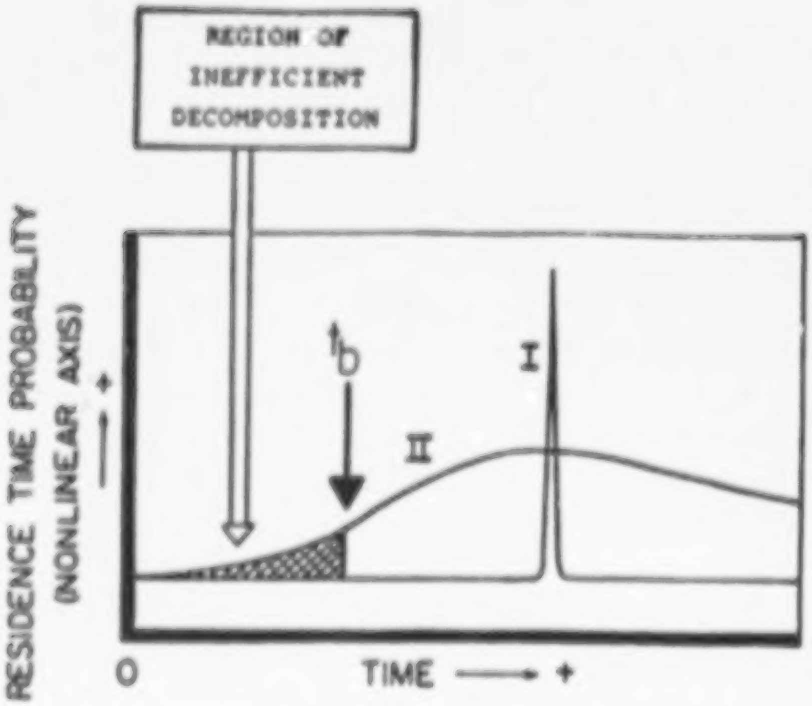

Figure 5.1. Hypothetical residence time distributions. Type I: plug flow velocities, Type II: wider dispersion of flow velocities.

$$H_z \xrightarrow{k_1} PIC \xrightarrow{k_2} \text{end products} \qquad \text{(Rxn 5.1)}$$

which assuming first order kinetics, yields the kinetic expression

$$\frac{[PIC]}{[H_z]_0} = \left[\frac{k_1}{k_2 - k_1}\right] \left[\exp\left(-A_1 t e^{-E_1/RT}\right) - \exp\left(-A_2 t e^{-E_2/RT}\right)\right] \qquad \text{(Eqn 5.1)}$$

These calculations revealed that for the same average temperature in the high-temperature zones, the positive temperature gradient shown in Figure 5.2b results in a lower PIC yield at the high temperature zone exit than the conventional negative gradient shown in Figure 5.2a.

Although Figure 5.2 is drawn with the position of the flame varied to achieve a modified temperature gradient, other engineering approaches can clearly be used with the same general result. We simply include this calculation to demonstrate how the understanding of PIC formation and destruction kinetics can be used to optimize incinerator design.

4. Slow quenching rate in cool zones may be utilized to minimize emissions of PICs formed by radical-radical (or atom) and radical-O_2 association reactions. Conventional rapid quenching (cf. Fig. 5.2a) tends to "freeze in" high radical concentrations exiting the high temperature zone by not allowing enough time at temperatures above 200°C for polyatomic radicals to decompose. These radicals can then only combine with other radicals or O_2 to produce PICs that are too stable to undergo further decomposition in the cool zone. By allowing a more gradual cooling (cf. Fig. 5.2b), the polyatomic radicals will have sufficient time at moderately elevated temperatures to decompose.

Introduction of more excess air tends to rapidly quench combustion gases and force the formation of oxidation-type PICs. Sufficient information is not available to assess if oxidation PICs are of lesser environmental consequence than recombination-type PICs.

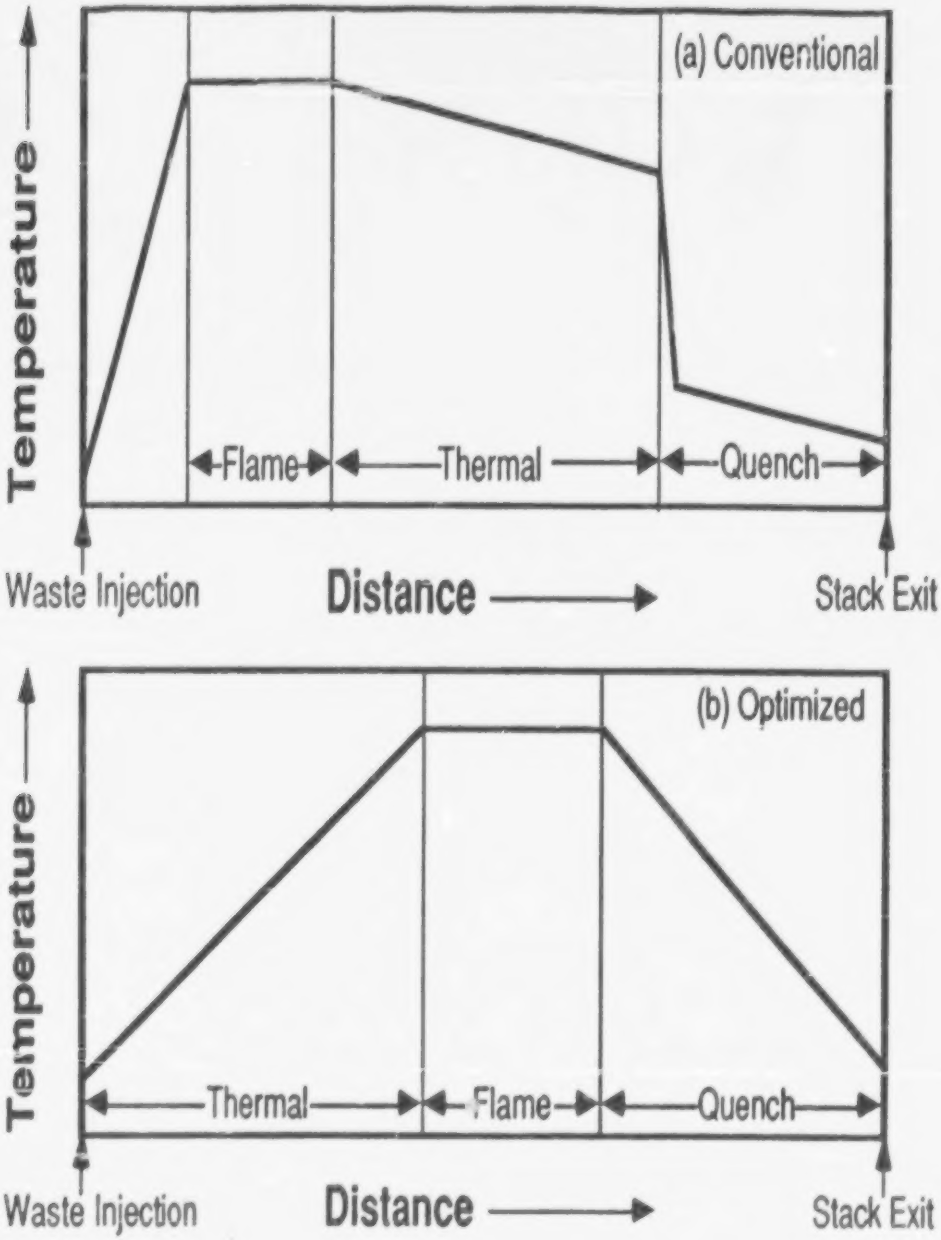
(a) Conventional
Temperature
Flame
Thermal
Quench
Waste Injection
Distance
Stack Exit
(b) Optimized
Temperature
Thermal
Flame
Quench
Waste Injection
Distance
Stack Exit

Figure 5.2. Schematic of hazardous waste incinerator temperature profiles. a) conventional profile, b) optimized profile.

Operation Implications

The following operation control concepts are based primarily on the present status of knowledge with regard to the thermal decomposition kinetic behavior of chlorinated hydrocarbons.

5. Low, chlorinated precursor concentrations are suggested to reduce toxic PIC formation due to molecular growth reactions involving Cl displacement. Although this suggestion seems obvious (but often difficult to implement), the concept, as proposed, is based on specific and non-obvious results of kinetic theory and experiment. As previously discussed, H will displace Cl much more rapidly than Cl will displace H. Calculation indicates that the Cl:H ratio must be in excess of 100 before a hydrocarbon PIC will undergo chlorination at combustion temperatures. Thus, the major route to formation of high molecular weight chlorinated PICs is through reactions of already chlorinated precursors. Since these reactions tend to be globally second-order with respect to precursor concentration it seems prudent (admittedly not always feasible) to simply dilute precursor concentration in the waste feed.

6. Low Cl:H ratios in the waste (or waste/fuel mixture) are expected to reduce PIC emissions due to radical-radical association reactions in the cool zone of the facility. Once again, this is a control option that is well known in the combustion community as a means of increasing flame stability. However, we are addressing a different aspect as related to PIC formation. This concept does not contradict the previous strategy because we are now addressing a different mechanism of PIC formation. Radicals produced in the high temperarure zones will recombine in the cool zone with any available radical. By simply keeping the Cl:H ratio low, one can also reduce the probability of association of organic radicals with Cl to produce chlorinated PICs. This, of course, assumes that association with H produces less toxic PICs. Once again, these association reactions tend to be second order and reducing the Cl:H ratio affords a quadratic reduction in chlorinated PIC concentration.

7. Waste homogenization to remove high chlorine pockets is essentially an extension of the arguments presented in operation implications 5 and 6. The major point is that a waste stream with a low bulk Cl:H ratio could nonetheless produce significant quantities of chlorinated PICs because of locally chlorine-rich pockets of waste that result from initially poor mixing. In a system where the overall Cl:H ratio is sufficiently low and the overall excess air level is representative of good combustion, these deviations from the nominal conditions have a low probability of causing significant emissions. Nonetheless, a "worst case" scenario could result from a locally high concentration of a highly toxic PIC precursor and the "right" reaction conditions. In this case, all of the emissions of toxic PICs could result from one small, high chlorine pocket.

Regulatory Implications

Although our understanding of PIC formation and discussion is far from complete, sufficient information may now be available to more directly address the PIC control issue.

8. "Comprehensive" emission modeling is suggested as a method for improving risk assessment and test-burn procedures for PICs. It now seems feasible to establish a reaction kinetic data base that can be used to model and predict the relative emission rates of residual POHCs and PICs from full-scale systems. This data base can be continually modified and improved as more kinetic data becomes available. A concerted effort to develop laboratory data on PIC yields and generate elementary reaction mechanisms and rate constants could produce data for 25-50 compounds per year. Standard, well-developed chemical kinetic and engineering analysis computer codes already exist that can be used in conjunction with the data base to generate an emissions estimate for the incineration of a complex waste mixture.

9. Limited test-burn testing for emissions of key PICs, as predicted by the modeling effort, can then be used to "calibrate" the relative emissions estimate. Specifically, the measured DREs of POHCs and the emission rates of PICs can be used to normalize the predicted emission rates for all of the

untested POHCs and PICs included in the model. As appropriate toxicological data becomes available, more accurate risk assessments can be conducted using these emissions estimates.

10. It is further suggested that the major PIC (or PICs) be continuously or periodically monitored to ensure facility compliance. Because of the lack of reliable PIC data and a reliable continuous monitoring system for organic PICs, EPA has proposed the use of CO and TUHC as PIC surrogates for continuous monitoring. These are valuable tools that can serve as an interim method of PIC control. However, it is not unreasonable to consider the development of a continuous monitor for organic PICs (benzene being the best currently identifiable choice) once a reliable PIC emissions data base has been established.

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APPENDIX A

AMERICAN CYANAMID INCINERATOR

SITE DESCRIPTION:

The American Cyanamid incinerator is an on-site facility designed to burn waste streams generated from chemical processes. Unit consists of a small chamber to mix the primary air with waste followed by a combustion chamber where secondary air is added. No APCDs are employed. Two different waste streams, an aniline waste and a mononitrobenzene waste were burned. Five runs were conducted for 1-2 hour burn periods each.

RESIDENCE TIME (CALCULATED):

0.17-0.24 s

TEMPERATURE:

629-779°C (3 feet from bottom of stack, average readings)
543-699°C (Sampling location, average readings)

OXYGEN (DRY BASIS):

10.3-13.1% (Continuous monitor, average readings for 4 runs)

CARBON DIOXIDE (DRY BASIS):

6.1-8.8% (Continuous monitor average readings for 4 runs)

WASTE FEED COMPOSITION:

Aniline waste: aniline, phenylenediamine, and diphenylamine
Mononitrobenzene waste: aniline, mononitrobenzene, and m-dinitrobenzene

WASTE FEED RATES (KG/MIN):

	Run 1	Run 2	Run 3	Run 4	Run 5
Aniline waste:	2.45	2.52	2.22	0	2.25
Mononitrobenzene waste:	0	0	0	3.17	0

CALCULATED POHC FEED RATES (G/MIN):

	Run 2	Run 3	Run 4	Run 5	Average
Aniline	1386	1332	13.82	1190	980.46
Phenylenediamine	5.8	11.77		10	9.19
Diphenylamine	15.62	12.88		12	13.50
Mononitrobenzene			20.28		20.28
m-Dinitrobenzene			9.83		9.83

AMERICAN CYANAMID INCINERATOR

UNCORRECTED POHC EMISSION RATES (G/MIN):

	Run 2	Run 3	Run 4	Run 5	Average
Aniline	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Phenylenediamine	< 0.0001	< 0.0001		< 0.0001	< 0.0001
Diphenylamine	< 0.0001	< 0.0001		< 0.0001	< 0.0001
Mononitrobenzene			0.0018		0.0018
m-Dinitrobenzene			< 0.001		< 0.001

UNCORRECTED VOLATILE PIC EMISSION RATES (G/MIN):

Gas Bags:	Run 1	Run 2	Run 3	Run 4	Run 5	Average
Chloroform	0.000072	0.0017	0.00016	0.000069	0.00002	0.000404
Benzene	< 0.00004	0.00032	0.0012	< 0.00003	0.00057	0.000697
Toluene	0.0017	0.0014	0.00072	0.00086	0.0012	0.001176
1,1,1-TCA [1]	< 0.000013	0.00012	< 0.000011	0.00014	0.000034	0.000098
Carbontetrachloride	0.000066	0.00003	0.00055	< 0.000012	0.000051	0.000174
TCE [1]	0.00079	0.00045	0.0031	0.00025	0.00042	0.001002
PCE [1]	0.000085	0.000077	0.000072	0.00014	0.000062	0.000087
CB [1]	0.000026	0.00044	0.0004	0.000029	0.00009	0.000197
VOST (1ST PAIR):						
Chloroform	0.000033	0.002	0.00054	0.00027	Not analyzed	0.000711
Benzene	0.00029	0.0023	0.0006	0.00043	Not analyzed	0.000905
Toluene	0.00066	0.0003	0.00055	0.00017	Not analyzed	0.000420
1,1,1-TCA [1]	< 0.0000033	0.00005	0.000004	0.000021	Not analyzed	0.000025
Carbontetrachloride	0.0003	0.0001	0.000061	0.000036	Not analyzed	0.000124
TCE [1]	0.0016	0.00096	0.0005	0.00028	Not analyzed	0.000835
PCE [1]	0.000014	0.000037	0.000012	0.0000094	Not analyzed	0.000018
CB [1]	0.00012	0.00032	0.00005	0.000058	Not analyzed	0.000137
VOST (AVERAGE OF THREE SAMPLES):						
Chloroform	0.000040	0.00107	0.000326	0.000164	Not analyzed	0.000400
Benzene	0.00017533	0.001355	0.000535	0.00032	Not analyzed	0.000596
Toluene	0.00033333	0.000191	0.0003695	0.0001195	Not analyzed	0.000253
1,1,1-TCA [1]	0.000079	0.0000275	0.000005	0.000021	Not analyzed	0.000033
Carbontetrachloride	0.00012533	0.0001	0.000074	0.000025	Not analyzed	0.000081
TCE [1]	0.00074333	0.00053	0.0003405	0.000182	Not analyzed	0.000449
PCE [1]	0.000013	0.0000255	0.0000085	0.0000094	Not analyzed	0.000014
CB [1]	0.000073	0.0001965	0.000046	0.0000465	Not analyzed	0.000091

Footnote:

1. 1,1,1-TCA = 1,1,1-trichloroethane; TCE = trichloroethylene; PCE = tetrachloroethylene; CB = chlorobenzene.

AMERICAN CYANAMID INCINERATOR

UNCORRECTED SEMIVOLATILE PIC EMISSION RATES (G/MIN):

	Run 1	Run 2	Run 3	Run 4	Run 5	Average
Naphthalene	Not analyzed	0.013	0.0014	0.004	0.0091	0.0061
o-Nitrophenol	Not analyzed	0.0086	< 0.0004	< 0.00036	< 0.0006	0.0086

EMISSIONS ANALYSES:

	POHC Emissions (max.)	PIC Emissions	PIC:POHC Ratio	% PIC Emissions (per POHC input)
Gas bags + semivolatiles				
Run 2	0.0001	0.026137	261.3700	0.0019
Run 3	0.0001	0.007602	76.0200	0.0006
Run 4	0.0018	0.005488	3.0489	0.0125
Run 5	0.0001	0.011547	115.4700	0.0010
VOST (averages) + semivolatiles				
Run 2	0.0001	0.0250955	250.9550	0.0018
Run 3	0.0001	0.0031045	31.0450	0.0002
Run 4	0.0018	0.0048874	2.7152	0.0111

CONTAMINATION:

CHC emissions inconsistent with waste feed composition; these compounds are likely produced from one of the following:

1. Stripping of volatile compounds from scrubber water
2. PICs from CHCs in waste whose concentrations are less than 100 ug/g.

COMMENTS:

Chloroform, toluene, benzene, trichloroethylene, o-nitrophenol, and naphthalene were the major PICs. Although PIC:POHC ratios in this study were higher than the other incinerators reviewed, the percentage of PIC emissions (per unit POHC feed rate) was >0.01% in only one of the four tests. Trace analysis of the waste streams was not conducted to determine if any low level CHCs were present. The relative importance of volatile compound stripping from scrubber water is difficult to assess in the absence of any analytical measurements. Although the incinerator did not employ APCDs for HCl and particulate removal, except for run 5, particulate emissions were below the federal regulation. Particulates were not tested for organic material.

DU PONT (LOUISIANA) INCINERATOR

SITE DESCRIPTION:

The Du Pont facility is an on-site incinerator at a chemical plant which also handles wastes from other Du Pont plants. Unit consists of two parallel incinerators discharging through a common scrubbing system. One of the components is a single stage liquid injection incinerator; the second is a rotary kiln incinerator with a natural gas-fired afterburner. Each unit has a water quench system and a cyclone which acts to remove particulate matter and droplets entrained in the exhaust. Three runs were conducted for these tests.

RESIDENCE TIME (CALCULATED):

7.0-7.6 s (kiln + afterburner)
0.25-0.28 s (liquid incinerator)

TEMPERATURE:

750-807°C (kiln exit)
967-1000°C (afterburner)
1450°C (refractory of liquid incinerator)

OXYGEN (DRY BASIS):

9.2-10.3% (continuous monitor, average readings for 3 runs)

CARBON DIOXIDE (DRY BASIS):

9.0-9.2% (continuous monitor, average readings for 3 runs)

WASTE FEED COMPOSITION:

Methylene chloride, chloroform, 1,1,1-trichloroethane, carbon tetrachloride, trichloroethylene, tetrachloroethylene, toluene, cis-1,4-dichlorobutene, trans-1,4-dichlorobutene, benzyl chloride, hexachloroethane, and naphthalene.

WASTE FEED RATES (KG/MIN):

	Run 1	Run 2	Run 3	Average
Liquid waste:	17.4	17.2	17.1	17.23
ISOM coke:	0.62	1.19	1.37	1.06
DCB coke:	0.087	0.53	1.46	0.69
Filter cake:	2.6	2.09	1.6	2.10
Paint waste:	1.27	1.23	1.19	1.23

APPENDIX A, cont.

DU PONT (LOUISIANA) INCINERATOR

CALCULATED POHC FEED RATES (G/MIN):

Volatile POHCs:	Run 1	Run 2	Run 3	Average
Methylene chloride	390	360	430	393.33
Chloroform	75	51	92	72.67
1,1,1-Trichloroethane	0.22			0.22
Carbon tetrachloride	1400	1200	1200	1266.67
Trichloroethylene	63	69	45	59.00
Tetrachloroethylene	240	190	190	206.67
Toluene	4900	4500	5000	4800.00
cis-1,4-Dichloro-2-butene	370	310	400	360.00
Semivolatile POHCs:				
trans-1,4-Dichloro-2-butene	1000	1000	1200	1066.67
Benzylchloride	48	52	50	50.00
Hexachloroethane	10	10	9	9.67
Naphthalene	2.5	2	1.3	1.93

UNCORRECTED POHC EMISSION RATES (G/MIN):

Volatile POHCs (gas bags):	Run 1	Run 2	Run 3	Average
Methylene chloride	0.0024	0.0013	0.0057	0.003133
Chloroform	0.0081	0.0071	0.0078	0.007667
1,1,1-Trichloroethane	< 0.000074	0.00035	< 0.000071	0.000350
Carbon tetrachloride	0.0036		0.0061	0.004850
Trichloroethylene	0.0052	0.0097	0.0053	0.006733
Tetrachloroethylene	0.0021	0.0015	0.01	0.004533
Toluene	0.013	0.0036	0.01	0.008867
cis-1,4-Dichloro-2-butene	< 0.000074	< 0.000075	< 0.000071	< 0.000071
Volatile POHCs (Fast VOST):				
Methylene chloride	0.0033	0.0018	0.0005	0.001867
Chloroform	0.0074	0.006	0.0076	0.007000
1,1,1-Trichloroethane	0.00016	0.000075	0.00011	0.000115
Carbon tetrachloride	0.0014	0.00086	0.003	0.001753
Trichloroethylene		0.00018	0.0009	0.000540
Tetrachloroethylene	0.0015	0.00079	0.0015	0.001263
Toluene	0.012	0.0034	0.005	0.006800
cis-1,4-Dichloro-2-butene	0.0011	< .00003	< 0.000043	0.001100

APPENDIX A, cont.

DU PONT (LOUISIANA) INCINERATOR

UNCORRECTED POHC EMISSION RATES (G/MIN):

Volatile POHCs (Slow VOST):				
Methylene chloride	0.0025	0.0037	0.0061	0.004100
Chloroform	0.0048	0.0071	0.0078	0.006567
1,1,1-Trichloroethane	< 0.00018	< 0.00015	< 0.00018	< 0.00015
Carbon tetrachloride	0.002	0.0015	0.0023	0.001933
Trichloroethylene		0.00071	0.0022	0.001455
Tetrachloroethylene	0.0013	0.00056	0.0015	0.001120
Toluene	0.0074	0.0037	0.0071	0.006067
cis-1,4-Dichloro-2-butene	< 0.000369	< 0.0015	< 0.00018	< 0.0015
Semivolatile POHCs:				
trans-1,4-Dichloro-2-butene	< 0.001	< 0.001	< 0.001	< 0.001
Benzylchloride	< 0.0004	< 0.0004	< 0.0004	< 0.0004
Hexachloroethane	< 0.001	< 0.001	< 0.001	< 0.001
Naphthalene	0.055	0.023	0.039	0.0390

APPENDIX A, cont.

DU PONT (LOUISIANA) INCINERATOR

UNCORRECTED VOLATILE PIC EMISSION RATES (G/MIN):

	Run 1	Run 2	Run 3	Average
Gas Bags:				
Benzene	0.12	0.037	0.14	0.099000
Chlorobenzene	0.0041	0.00075	0.0021	0.002317
Bromodichloromethane	0.0021	0.00097	0.0011	0.001390
Dibromochloromethane	0.00052	0.0003	0.00093	0.000583
Bromoform	< 0.000074	< 0.000075	0.00014	0.000140
Fast VOST (1st pair):				
Benzene	0.81	0.0035	0.027	0.280200
Chlorobenzene	0.0037	0.0003	0.0014	0.001800
Bromodichloromethane	0.0014	0.00045	0.00082	0.000890
Dibromochloromethane	0.00041	0.00037	0.00046	0.000413
Bromoform	0.00081	0.000045	0.00023	0.000362
Fast VOST (average of six samples):				
Benzene	0.59	0.1	0.046	0.245333
Chlorobenzene	0.0036	0.00071	0.0014	0.001903
Bromodichloromethane	0.0016	0.00079	0.001	0.001130
Dibromochloromethane	0.00025	0.00037	0.0005	0.000373
Bromoform	0.000044	0.000037	0.00015	0.000077
Slow VOST (1st pair):				
Benzene	0.44	0.0041	0.046	0.163400
Chlorobenzene	0.001	0.00023	0.00014	0.000457
Bromodichloromethane	0.00055	0.00026	0.00082	0.000543
Dibromochloromethane	< 0.00015	< 0.00022	0.00043	0.000430
Bromoform	< 0.00015	< 0.00015	< 0.00018	< 0.00018
Slow VOST (average of six samples):				
Benzene	0.41	0.033	0.056	0.166333
Chlorobenzene	0.0017	0.0011	0.0012	0.001333
Bromodichloromethane	0.001	0.00034	0.00096	0.000767
Dibromochloromethane	0.00016	< 0.00034	0.00032	0.000240
Bromoform	< 0.00015	< 0.00015	< 0.00014	< 0.00015

UNCORRECTED SEMIVOLATILE PIC EMISSION RATES (G/MIN):

	Run 1	Run 2	Run 3	Average
Phenol	0.008	0.007	0.01	0.008333

DU PONT (LOUISIANA) INCINERATOR

EMISSIONS ANALYSES:

	POHC Emissions	PIC Emissions	PIC:POHC Ratio	% PIC EMISSIONS (per POHC input)	% CIPIC EMISSIONS (per CIPOHC input)
Gas bags + semivolatiles					
Run 1	0.089400	0.134720	1.506935	0.001585	0.000187
Run 2	0.046550	0.046020	0.988614	0.000594	0.000062
Run 3	0.083900	0.154270	1.838737	0.001790	0.000114
Fast VOST + semivolatiles					
Run 1	0.081860	0.603494	7.372270	0.007101	0.000152
Run 2	0.036105	0.108907	3.016397	0.001406	0.000001
Run 3	0.057610	0.059050	1.024996	0.000685	0.000080
Slow VOST + semivolatiles					
Run 1	0.073000	0.420860	5.765205	0.004952	0.000080
Run 2	0.040270	0.041440	1.029054	0.000535	0.000044
Run 3	0.066000	0.068480	1.037576	0.000795	0.000069

CONTAMINATION:

Brominated emissions inconsistent with waste feed composition; these compounds are likely produced from one of the following:

1. Stripping of volatile compounds from scrubber water
2. PICs from brominated compounds in waste whose concentrations are less than 100 ug/g.

COMMENTS:

Benzene, phenol, and chlorobenzene were the major PICs observed. The percentage of PIC emissions (per unit POHC feed rate) were <0.01% for every test. A majority of PIC:POHC ratios were very close to unity. Trace analysis of the waste streams was not conducted to determine if any low level brominated compounds were present. The relative importance of volatile compound stripping from the scrubber water is difficult to assess in the absence of any analytical measurements. Average particulate emissions (23 mg/dscm) were well below the federal regulation. Particulates were not analyzed for organic matter.

MITCHELL SYSTEMS INCINERATOR

SITE DESCRIPTION:

Off-site facility designed primarily to burn liquid wastes; also has the capability to accept small quantities of solid wastes. Unit consists of two horizontally-oriented, cylindrical combustion chambers (primary and secondary) situated one above the other. No scrubbers or other APCDs employed. During the 4 tests, only liquid wastes were burned using air-atomized injectors.

RESIDENCE TIME (CALCULATED):

2.2-2.5 s (primary + secondary chamber)

TEMPERATURE:

1053-1094°C (secondary chamber)
1011-1122°C (primary chamber)

OXYGEN (DRY BASIS):

9.4-10.8% (continuous monitor, average of readings for 3 runs)

CARBON DIOXIDE (DRY BASIS):

7.4-8.5% (continuous monitor, average readings for 3 runs)

WASTE FEED COMPOSITION:

Carbon tetrachloride, trichloroethylene, benzene, methyl ethyl ketone, tetrachloroethylene, toluene, phenol, isophorone, naphthalene, butyl benzyl phthalate, and bis(2-ethylhexyl) phthalate.

WASTE FEED RATES (KG/MIN):

	Run 1	Run 2	Run 3	Run 4	Average
Organic waste:	3.76	4.01	4.5	4.25	4.13
Aqueous waste:	6.13	5.38	4.9	5.61	5.51

CALCULATED POHC FEED RATES (G/MIN):

Volatile POHCs:	Run 1	Run 2	Run 3	Run 4	Average
Carbon tetrachloride	24	25	21	24	23.50
Trichloroethylene	22	22	19	22	21.25
Benzene	0.01	1.1	0.63	0.36	0.53
Toluene	7.3	10	9	6.1	8.10
Methyl ethyl ketone	27	40	33	28	32.00
Tetrachloroethylene	0.064	0.012	0.81	0.21	0.27

APPENDIX A, cont.

MITCHELL SYSTEMS INCINERATOR

CALCULATED POHC FEED RATES (G/MIN):

Semivolatile POHCs:					
Phenol	270	180	Not analyzed	170	206.67
Isophorene	< 1	0.45	Not analyzed	2.1	1.28
Naphthalene	1.9	1.4	Not analyzed	3.9	2.40
Butyl benzyl phthalate	0.75	1.3	Not analyzed	0.64	0.90
bis(2-ethylhexyl)phthalate	19	16	Not analyzed	41	25.33

UNCORRECTED POHC EMISSION RATES (G/MIN):

Volatile POHCs:	Run 1	Run 2	Run 3	Run 4	Average
Gas bags					
Carbon tetrachloride	0.00074	0.00055	0.00091	0.00054	0.000685
Trichloroethylene	0.0077	0.0064	0.0047	0.0035	0.005575
Benzene	0.00055	0.00026	0.00072	0.00066	0.000548
Tetrachloroethylene	0.00015	0.000088	0.00013	0.000087	0.000114
Toluene	0.0048	0.002	0.0015	0.0018	0.002525
Methyl ethyl ketone	0.0016	0.0011	0.0019	0.0039	0.002125
Fast VOST					
Carbon tetrachloride	0.00008	0.00014	0.00012	No analysis	0.000113
Trichloroethylene	0.00057	0.0005	0.00018	No analysis	0.000417
Benzene	0.00016	0.0003	0.00054	No analysis	0.000333
Tetrachloroethylene	< 0.000008	< 0.000007	< 0.00001	No analysis	< 0.00001
Toluene	0.00023	0.00084	0.00084	No analysis	0.000637
Methyl ethyl ketone	0.00012	0.00038	0.00073	No analysis	0.000410
Slow VOST					
Carbon tetrachloride	0.00071	0.0025	0.0034	No analysis	0.002203
Trichloroethylene	0.0033	0.0021	0.00076	No analysis	0.002053
Benzene	0.00053	0.0012	0.0012	No analysis	0.000977
Tetrachloroethylene	< 0.00005	< 0.00002	< 0.00006	No analysis	< 0.00002
Toluene	0.0026	0.0061	0.0042	No analysis	0.004300
Methyl ethyl ketone	0.001	0.0021	0.0042	No analysis	0.002433
Semivolatile POHCs:					
Phenol	0.0041	< 0.00004	0.00062	No analysis	0.002360
Isophorene	Anal. Interfer.	Anal. Interfer.	Anal. Interfer.	No analysis	
Naphthalene	0.001	0.00051	0.00077	No analysis	0.000760
Butyl benzyl phthalate	< 0.00003	0.000032	0.000168	No analysis	0.000100
bis(2-ethylhexyl)phthalate	0.0004	0.00126	0.00165	No analysis	0.001103

MITCHELL SYSTEMS INCINERATOR

UNCORRECTED VOLATILE PIC EMISSION RATES (G/MIN):

Gas Bags:	Run 1	Run 2	Run 3	Run 4	Average
Methylene chloride	0.00067	0.00081	0.0002	0.0016	0.00082
Chloroform	0.000051	0.000021	0.000019	0.000024	0.00002875
1,1,1-Trichloroethane	0.00013	0.0001	0.000037	0.000035	0.0000755
Chlorobenzene	0.00092	0.00079	0.00047	0.00079	0.0007425
Fast VOST (1st pair) [1]:					
Methylene chloride	0.000047	0.00058	0.00012	No analysis	0.000249
Chloroform	0.000059	0.000075	0.0001	No analysis	0.000078
1,1,1-Trichloroethane	0.0000039	0.000016	0.0000049	No analysis	0.000008
Chlorobenzene	0.000026	0.000084	0.000076	No analysis	0.000062

UNCORRECTED VOLATILE PIC EMISSION RATES (G/MIN):

Fast VOST (Average of 6 samples) [1]:					
Methylene chloride	0.000046	0.00028	0.00012	No analysis	0.000148666667
Chloroform	0.000095	0.00015	0.000092	No analysis	0.000112333333
1,1,1-Trichloroethane	< 0.000005	0.000015	< 0.000005	No analysis	0.000015
Chlorobenzene	0.000071	0.000099	0.000071	No analysis	0.000080
Slow VOST (1st pair) [1]:					
Methylene chloride	0.00045	0.0023	0.0031	No analysis	0.00195
Chloroform	0.00039	0.00023	0.0071	No analysis	0.002573333333
1,1,1-Trichloroethane	0.000095	0.000099	0.00015	No analysis	0.000114666667
Chlorobenzene	0.0001	0.00007	0.00017	No analysis	0.000113333333
Slow VOST (Average of 6 samples) [1]:					
Methylene chloride	< 0.0016	0.0016	0.0014	No analysis	0.0015
Chloroform	0.0002	0.00099	0.003	No analysis	0.001396666667
1,1,1-Trichloroethane	< 0.00006	0.000084	0.0001	No analysis	0.000092
Chlorobenzene	0.000061	0.00061	0.00018	No analysis	0.000283666667

Footnote:

1. The 1st, 3rd, and 6th pairs of the fast VOST corresponds to the 1st, 2nd, and 3rd pairs of the slow VOST, respectively.

UNCORRECTED SEMIVOLATILE PIC EMISSION RATES (G/MIN):

	Run 1	Run 2	Run 3	Run 4	Average
2,4-Dimethylphenol	< 0.00005	0.0016	Not analyzed	< 0.00007	0.0016

APPENDIX A, cont.
MITCHELL SYSTEMS INCINERATOR

EMISSIONS ANALYSES:

	POHC Emissions	PIC Emissions	PIC:POHC Ratio	% PIC Emissions (per POHC input)	% CIPIC Emissions (per CIPOHC input)
Gas bags + semivolatiles					
Run 1	0.021040	0.001771	0.084173	0.000476	0.003845
Run 2	0.012200	0.003321	0.272213	0.001117	0.003578
Run 3	0.013068	0.000726	0.055556	0.000870	0.001787
Run 4	0.010487	0.002449	0.233527	0.000821	0.005283
Fast VOST + semivolatiles					
Run 1	0.006660	0.000212	0.031832	0.000057	0.000460
Run 2	0.003962	0.002144	0.541141	0.000721	0.001131
Run 3	0.005618	0.000283	0.050374	0.000339	0.000697
Slow VOST + semivolatiles					
Run 1	0.013640	0.000261	0.019135	0.000070	0.000567
Run 2	0.015802	0.004884	0.309075	0.001643	0.006827
Run 3	0.016968	0.004680	0.275813	0.005609	0.011519

CONTAMINATION:

Contamination not evident based on emissions measurements. Scrubber makeup water was not analyzed for organics.

COMMENTS:

Dichloromethane and chloroform were the major PICs observed. The percentage of PIC emissions (per unit POHC input) were <0.01% for all tests. PIC:POHC ratios were also much less than unity. Particulate emissions averaged 903 mg/dscm, 5 times the the federal particulate emission limitation. Analysis of particulates for organic material was not conducted.

ROSS INCINERATION SERVICES

UNCORRECTED VOLATILE PIC EMISSION RATES (G/MIN):

		Run 1	Run 2	Run 3	Average
Gas bags:	Chloroform [1]	0.0064	0.0076	0.0074	0.0071
	Benzene [1]	0.009	0.016	0.019	0.0147
	Bromomethane [2]	0.006	0.00094	0.00062	0.0025
	Chloromethane [2]	0.18	0.038	0.059	0.0923
	Carbon disulfide [2]	0.021	0.0028	0.0034	0.0091
	Bromochloromethane [2]	0.009	0.03	0.039	0.0260
	Methylene bromide [2]	0.0075	0.0095	0.014	0.0103
	Bromodichloromethane [2]	0.0039	0.0055	0.0028	0.0041
	Dibromochloromethane [2]	0.0021	0.0012	0.0023	0.0019
	Bromoform [2]	0.005	0.0036	0.0051	0.0046
VOST:					
	Chloroform [1]	0.008	0.0079	0.00475	0.0069
	Benzene [1]	0.0062	0.01223333	0.00695	0.0085
	Bromomethane [2]	0.00024	0.005	0.001065	0.0021
	Chloromethane [2]	0.0033	0.0046	0.0036	0.0038
	Carbon disulfide [2]	0.036	0.03266667	0.013	0.0272
	Bromochloromethane [2]	0.016	0.01633333	0.0155	0.0159
	Methylene bromide [2]	0.009	0.016	0.021	0.0153
	Bromodichloromethane [2]	0.0043	0.0046	0.0051	0.0047
	Dibromochloromethane [2]	0.00231	0.00393333	0.0059	0.0040
	Bromoform [2]	0.003665	0.00973333	0.01025	0.0079

UNCORRECTED SEMIVOLATILE PIC EMISSION RATES (G/MIN):

	Run 1	Run 2	Run 3	Average
Fluoranthene [1]	0.00012	0.001	0.001	0.0007
Pyrene [1]	0.0011	< 0.0004	0.001	0.0011

Footnotes to POHC input, POHC output and PIC output data:

1. Quantitated against authentic standard.
2. Semiquantitated based on total ionization relative to internal standard.
3. Dimethylacetamide is not on the Appendix VIII list but was of interest to EPA.

ROSS INCINERATION SERVICES

SITE DESCRIPTION:

Off-site facility designed primarily to burn solid and liquid wastes. Unit consists of a rotary kiln and a large, rectangular combustion chamber. APCDs include a water quench section, two packed scrubbers, and a two-stage ionizing wet scrubber. Three runs were conducted for these tests burning four widely different liquid, aqueous, and solid waste streams.

RESIDENCE TIME (CALCULATED):

6.2-6.7 s (combustion chamber)

TEMPERATURE:

1117-1154°C (combustion chamber)
132°C (exit dry quench)
71-74°C (into 1st absorber)
56-59°C (stack)

OXYGEN (DRY BASIS):

10.4-10.7% (continuous monitor, average readings for 3 runs)

CARBON DIOXIDE (DRY BASIS):

7.9-8.3% (continuous monitor, average readings for 3 runs)

WASTE FEED COMPOSITION:

Methylene chloride, carbon tetrachloride, trichloroethylene, tetrachloroethylene, toluene, methyl ethyl ketone, 1,1,1-trichloroethane, 1,1,2-trichloroethane, N,N-dimethyl acetamide, phenol, 2,4-dimethyl phenol, naphthalene, butyl benzyl phthalate, phthalic anhydride, aniline, methyl pyridine, and cresol isomers.

WASTE FEED RATES (KG/MIN):

	Run 1	Run 2	Run 3	Average
Organic waste:	40.3	36	35.4	37.23
Aqueous waste:	35.2	36.9	36.1	36.07
Drum Waste to Kiln:	10.9	13.7	11	11.87
Drum waste to chamber:	13.6	11.3	15.9	13.60

ROSS INCINERATION SERVICES

CALCULATED POHC FEED RATES (G/MIN):				
Volatile POHCs [1]:	Run 1	Run 2	Run 3	Average
Carbon tetrachloride	160	210	200	190
Trichloroethylene	1040	460	820	773.33
Tetrachloroethylene	780	680	1640	1033.33
Toluene	4040	2810	2700	3183.33
Volatile POHCs [2]:				
Methylene chloride	230	660	350	413.33
Methyl ethyl ketone	860	770	1610	1080
1,1,1-Trichloroethane	2550	890	570	1336.67
1,1,2-Trichloroethane	35	27	37	33
Semivolatile POHCs [1]:				
N,N-Dimethylacetamide [3]	830	1780	1870	1493.33
Phenol	12	6	5	7.67
2,4-Dimethylphenol	20	20	70	36.67
Naphthalene	32	35	24	30.33
CALCULATED POHC FEED RATES (G/MIN):				
Semivolatile POHCs [2]:				
Butyl benzyl phthalate	100	17	27	48
Phthalic anhydride		8	7	7.5
Aniline	26	21	26	24.33
Methyl pyridine	25	41	40	35.33
Cresol isomers	120	73	90	94.33

ROSS INCINERATION SERVICES

UNCORRECTED POHC EMISSION RATES (G/MIN):

	Run 1	Run 2	Run 3	Average
Gas Bag-Volatile POHCs [1]:				
Carbon tetrachloride	0.011	0.063	0.074	0.0493
Trichloroethylene	0.11	0.3	0.43	0.2800
Tetrachloroethylene	0.0065	0.0068	0.0085	0.0073
Toluene	0.026	0.041	0.085	0.0507
Gas Bag-Volatile POHCs [2]:				
Methylene chloride	0.009	1.2	0.93	0.3568
Methyl ethyl ketone	0.00049	0.00063	0.00078	0.0167
1,1,1-Trichloroethane	0.0073	0.041	0.05	0.0242
1,1,2-Trichloroethane	< 0.0002	< 0.0002	< 0.0002	< 0.0002
VOST-Volatile POHCs [1]:				
Carbon tetrachloride	0.00695	0.01295	0.0097	0.0099
Trichloroethylene	0.0075	0.0263	0.02765	0.0205
Tetrachloroethylene	0.01145	0.01085	0.01565	0.0127
Toluene	0.0376	0.0535	0.0625	0.0512
VOST-Volatile POHCs [2]:				
Methylene chloride	0.073	0.194	0.016	0.0943
Methyl ethyl ketone	0.003	0.00825	0.0115	0.0076
1,1,1-Trichloroethane	0.0155	0.01735	0.0059	0.0129
1,1,2-Trichloroethane	< 0.0004	< 0.0004	< 0.0004	< 0.0004
Semivolatile POHCs [1]:				
N,N-Dimethylacetamide [3]	< 0.002	< 0.002	< 0.002	< 0.002
Phenol	< 0.0004	< 0.0004	< 0.0004	< 0.0004
2,4-Dimethylphenol	0.0002	0.0002	< 0.0004	0.0002
Naphthalene	< 0.002	< 0.002	< 0.002	< 0.002
Semivolatile POHCs [2]:				
Butyl benzyl phthalate	< 0.0004	< 0.0004	< 0.0004	< 0.0004
Phthalic anhydride	< 0.0008	< 0.0007	< 0.0008	< 0.0007
Aniline	< 0.0004	< 0.0004	< 0.0004	< 0.0004
Methyl pyridine	< 0.0004	< 0.0004	< 0.0004	< 0.0004
Cresol isomers	< 0.0008	< 0.0007	< 0.0008	< 0.0007

ROSS INCINERATION SERVICES

EMISSIONS ANALYSES:

	POHC Emissions	PIC Emissions	PIC:POHC Ratio	% PIC Emissions (per POHC input)	% CIPIC Emissions (per CIPOHC input)
Gas bags + Semivolatiles					
Run 1	0.170490	0.251120	1.472931	0.002312	0.004200
Run 2	1.652630	0.116140	0.070276	0.001365	0.002812
Run 3	1.578280	0.154620	0.097967	0.001533	0.003055
VOST + Semivolatiles					
Run 1	0.155200	0.090235	0.581411	0.000831	0.000707
Run 2	0.323400	0.114000	0.352505	0.001340	0.001277
Run 3	0.148900	0.089115	0.598489	0.000884	0.000964

CONTAMINATION:

Brominated emissions inconsistent with waste feed composition; these compounds are likely produced from one of the following:

1. Stripping of volatile compounds from scrubber water
2. PICs from brominated compounds in waste whose concentrations are less than 100 ug/g.

COMMENTS:

Chloromethane was the major PIC observed. The percentage PIC emissions (per unit POHC input) were <0.01% for every test. With the exception of run 1 (gas bag sample), PIC:POHC ratios were much less than unity. Trace analysis of the waste streams was not conducted to determine if any low level brominated compounds were present. The relative importance of volatile compound stripping from scrubber water is difficult to assess in the absence of any analytical measurements. Particulate emissions were below the federal regulation. Particulates were not tested for organic material.

TWI INCINERATOR

SITE DESCRIPTION:

Off-site facility that burns liquid and solid wastes. Incinerator design features a two-stage combustion chamber, a quench section, a Venturi scrubber and a packed scrubber. Primary combustion chamber can accept solid and liquid wastes through separate feed systems. Fuel oil and combustion air are admitted into both the primary and secondary chamber to maintain desired operating conditions. After exiting the secondary chamber, the gases are quenched and passed through a venturi scrubber for particulate and HCl removal. The gases then travel through a mist eliminator. Four runs were conducted for these tests burning three organic, aqueous, and solid waste streams.

RESIDENCE TIME (CALCULATED):

3.0-4.7 s (primary and secondary combustion chamber)

TEMPERATURE:

988-1130°C (primary combustion chamber)
965-1110°C (secondary combustion chamber)
73-80°C (prequench)
52-66°C (stack gas)

OXYGEN (DRY BASIS):

12.4-15.6% (continuous monitor, spread of readings for 4 runs)

CARBON DIOXIDE (DRY BASIS):

3.9-6.6% (continuous monitor, average readings for 4 runs)

WASTE FEED COMPOSITION:

Methylene chloride, methylene bromide, chloroform, carbon tetrachloride, 1,1,1-trichloroethane, trichloroethylene, tetrachloroethylene, toluene, benzene, chlorobenzene, hexachlorocyclopentadiene, bis(2-ethylhexyl)phthalate, chlordane (runs 1-3), naphthalene (run 4), and hexachlorobutadiene (run 4)

WASTE FEED RATES (KG/MIN):

	Run 1	Run 2	Run 3	Run 4
Organic waste:	3.17	3.24	2.6	1.05
Aqueous waste:	8.1	5.06	3.83	2.55
Solid waste (sand/gravel with chlordane)	3.89	4.43	4.03	
High Btu solids with C-56:				4.05
Fuel Oil:	1	1.4	2.5	1.2

TWI INCINERATOR

CALCULATED POHC FEED RATES (G/MIN) [1]:

Volatile POHCs:	Run 1	Run 2	Run 3	Run 4 [2]	Average
Methylene chloride	0.95	0.97	2.2	0.89	1.2525
Chloroform	0.34	0.36	0.21	0.5	0.3525
Methylene bromide	3.7	16	18	12	12.425
1,1,1-Trichloroethane	1.2	1.4	1.1	0.39	1.0225
Carbon tetrachloride	30	29	29	29	29.25
Trichloroethylene	27	27	27	27	27
Benzene	230	150	150	68	149.5
Tetrachloroethylene	0.86	0.81	1.3	1.4	1.0925
Toluene	1200	520	1000	460	795
Chlorobenzene	1.3	1.3	1	0.36	0.99
Semivolatile POHCs:					
Hexachlorocyclopentadiene	1	1	1	53	14
bis(2-ethylhexyl)phthalate	0.65	0.65	0.6	0.2	0.525
Chlordane	70	84	77	< 0.1	77
Naphthalene	< 0.1	< 0.1	< 0.1	29	29
Hexachlorobutadiene	< 0.1	< 0.1	< 0.1	1.1	1.1
Total:	1567.0	832.5	1308.4	682.8	
ClPOHC Feedrate:	132.7	145.8	139.8	142.6	

Footnotes:

1. These input rates include POHCs found in the fuel oil.
2. Run 4 used a different solid waste feed than runs 1-3.

NOT BLANK CORRECTED POHC EMISSION RATES (G/MIN):

Volatile POHCs:

Gas bags:	Run 1	Run 2	Run 3	Run 4	Average
Methylene chloride	No analysis	0.0025	0.0026	0.0084	0.004500
Chloroform	No analysis	0.00056	0.00067	0.0025	0.001243
Methylene bromide	No analysis	< 0.00007	0.00091	0.0038	0.002355
1,1,1-Trichloroethane	No analysis	0.00069	0.00062	0.0019	0.001070
Carbon tetrachloride	No analysis	< 0.0001	0.0002	0.00035	0.000275
Trichloroethylene	No analysis	0.0041	0.0018	0.0017	0.002533
Benzene	No analysis	0.0011	0.0058	0.013	0.006633
Tetrachloroethylene	No analysis	0.00049	0.00091	0.0009	0.000767
Toluene	No analysis	0.0025	0.011	0.073	0.028833
Chlorobenzene	No analysis	< 0.00007	0.00014	0.00037	0.000255

APPENDIX A, cont.

TWI INCINERATOR

NOT BLANK CORRECTED POHC EMISSION RATES (G/MIN):

Gas bags (grab samples):					
Methylene chloride	0.0069	0.0048	No analysis	No analysis	0.005850
Chloroform	0.0073	0.0029	No analysis	No analysis	0.005100
Methylene bromide	0.00017	0.00015	No analysis	No analysis	0.000160
1,1,1-Trichloroethane	0.003	0.0023	No analysis	No analysis	0.002650
Carbon tetrachloride	0.00019	< 0.0001	No analysis	No analysis	0.000190
Trichloroethylene	0.0022	0.0026	No analysis	No analysis	0.002400
Benzene	0.0086	0.01	No analysis	No analysis	0.009300
Tetrachloroethylene	0.0024	0.0014	No analysis	No analysis	0.001900
Toluene	0.028	0.022	No analysis	No analysis	0.025000
Chlorobenzene	0.0071	0.0018	No analysis	No analysis	0.004450

NOT BLANK CORRECTED POHC EMISSION RATES (G/MIN):

Fast VOST (average):					
Methylene chloride	0.00092	0.0044	0.0028	0.004	0.003030
Chloroform	0.00022	0.0065	0.0047	0.0012	0.003155
Methylene bromide	0.00005	0.0007	0.0066	0.0021	0.002363
1,1,1-Trichloroethane	0.00042	0.0027	0.0015	0.00089	0.001378
Carbon tetrachloride	0.00049	0.0005	0.00039	0.00044	0.000455
Trichloroethylene	0.001	0.0016	0.0009	0.0003	0.000950
Benzene	0.001	0.016	0.024	0.0083	0.012325
Tetrachloroethylene	0.0003	0.0022	0.0015	0.00025	0.001063
Toluene	0.006	0.049	0.049	0.037	0.035250
Chlorobenzene	0.0006	0.0039	0.00044	0.00013	0.001268
Slow VOST (average):					
Methylene chloride	0.00745	0.0012	0.0032	No analysis	0.003950
Chloroform	0.003515	0.009	0.0055	No analysis	0.006005
Methylene bromide	0.00032	0.00084	0.0045	No analysis	0.001887
1,1,1-Trichloroethane	0.00255	0.0039	0.0019	No analysis	0.002783
Carbon tetrachloride	0.0011	0.0005	0.0004	No analysis	0.000667
Trichloroethylene	0.00425	0.0018	0.0007	No analysis	0.002250
Benzene	0.01055	0.01	0.014	No analysis	0.011517
Tetrachloroethylene	0.0027	0.0022	0.0016	No analysis	0.002167
Toluene	0.017	0.019	0.012	No analysis	0.016000
Chlorobenzene	0.00445	0.0032	0.0006	No analysis	0.002750

TWI INCINERATOR

NOT BLANK CORRECTED POHC EMISSION RATES (G/MIN):

Semivolatile POHCs:					
Hexachlorocyclopentadiene	< 0.0002	< 0.0002	< 0.0002	< 0.0003	< 0.0003
bis(2-ethylhexyl)phthalate	0.00066	0.0006	0.0007	0.00059	0.0006375
Chlordane	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002
Naphthalene				0.0011	0.0011
Hexachlorobutadiene				< 0.0003	< 0.0003

NOT BLANK CORRECTED VOLATILE PIC EMISSION RATES (G/MIN):

Gas Bags:	Run 1	Run 2	Run 3	Run 4	Average
Bromochloromethane	No analysis	< 0.00007	< 0.00005	< 0.0020	0.002364
Bromodichloromethane	No analysis	< 0.0001	< 0.0001	0.0011	0.002035
Dibromochloromethane	No analysis	< 0.0001	< 0.0001	0.0012	0.001867166667
Bromoform	No analysis	< 0.0001	0.00022	0.009	0.001757166667
Gas bags [1]:					
Bromochloromethane	No analysis	0.0003	No analysis	No analysis	0.0003
Bromodichloromethane	No analysis	0.00039	No analysis	No analysis	0.00039
Dibromochloromethane	No analysis	0.000093	No analysis	No analysis	0.000093
Bromoform	No analysis	0.00054	No analysis	No analysis	0.00054
Fast VOST (1st pair):					
Bromochloromethane	0.00022	0.00078	0.00077	Not reported	0.00059
Bromodichloromethane	0.0008	0.00074	0.0012	Not reported	0.000913333333
Dibromochloromethane	< 0.00002	0.00026	0.00085	Not reported	0.000555
Bromoform	< 0.00002	0.00063	0.0014	Not reported	0.001015
Fast VOST (average of 6 pairs):					
Bromochloromethane	0.000065	0.00084	0.001	0.0011	0.00075125
Bromodichloromethane	0.000026	0.00058	0.0012	0.00059	0.000599
Dibromochloromethane	0.0000023	0.00029	0.0011	0.00037	0.000440575
Bromoform	0.000098	0.002	0.01	0.0016	0.0034245

TWI INCINERATOR

NOT BLANK CORRECTED VOLATILE PIC EMISSION RATES (G/MIN):

Slow VOST (1st pair):					
Bromochloromethane	0.00063	0.00011	0.00074	No analysis	0.000493333333
Bromodichloromethane	0.000095	0.0011	0.0016	No analysis	0.000931666667
Dibromochloromethane	0.000064	0.0014	0.0015	No analysis	0.000988
Bromoform	0.00036	0.006	0.0057	No analysis	0.00402
Slow VOST (average of 2 pairs):					
Bromochloromethane	See footnote 2	0.0007	0.00085	No analysis	0.000775
Bromodichloromethane	See footnote 2	0.0016	0.00126	No analysis	0.00143
Dibromochloromethane	See footnote 2	0.0011	0.001035	No analysis	0.0010675
Bromoform	See footnote 2	0.0044	0.00785	No analysis	0.006125

Footnote:

1. This sample was a grab sample; this analysis was only performed for run 2.
2. Only one slow VOST sample was obtained for run 1.

NOT BLANK CORRECTED SEMIVOLATILE PIC EMISSION RATES (G/MIN):

	Run 1	Run 2	Run 3	Run 4	Average
Naphthalene [1]	0.0035	0.0017	0.00058	-	0.001926666667

Footnote:

1. Naphthalene was found in concentrations greater than 100 ug/g in the waste feed in run 4.

TWI INCINERATOR

EMISSIONS ANALYSES:

	POHC Emissions	PIC Emissions	Total Emissions	PIC:POHC Ratio	CIPIC Emissions	% PIC EMISSIONS (per POHC input)	% CIPIC Emissions (per CIPOHC input)	% PIC Emissions (per Waste input)
Gas bags + semivolatiles:								
Run 2	0.012540	0.001700	0.01424	0.1355662		0.0002		
Run 3	0.025350	0.000800	0.02615	0.0315582		0.0001		
Run 4	0.107610	0.011300	0.11891	0.1050088		0.0017		
Grab samples + semivolatiles:								
Run 2	0.048550	0.003023	0.051573	0.0622657		0.0004		
Fast VOST (average) + semivolatiles:								
	0.011660	0.003691	0.0153513	0.3165780	0.000093	0.0002	7.03E-05	2.43E-05
	0.088100	0.005410	0.09351	0.0614075	0.001710	0.0006	1.17E-03	4.25E-05
	0.092530	0.013880	0.10641	0.1500054	0.003300	0.0011	2.36E-03	1.33E-04
	0.056300	0.003660	0.05996	0.0650089	0.002060	0.0005	1.44E-03	4.78E-05
Slow VOST (average) + semivolatiles:								
Run 1	0.054545	0.004649	0.059194	0.0852324		0.0003		
Run 2	0.05224	0.0095	0.06174	0.1818530		0.0011		
Run 3	0.0451	0.011575	0.056675	0.2566519		0.0009		

	POHC Feedrates (g/min)	CLPOHC feedrate (g/min)	Waste Feedrates (g/min)	Total Feedrate (g/min)	Naphthalene (g/min)	% Naph Emissions (per POHC input)	% Naph Emissions (per total input)	% Emissions (per total input)
Run 1	1567.0	132.7	15160	16160	0.0035	2.23E-04	2.17E-05	9.50E-05
Run 2	832.5	145.8	12730	14130	0.0017	2.04E-04	1.20E-05	6.62E-04
Run 3	1308.4	139.8	10460	12960	0.00058	4.43E-05	4.48E-06	8.21E-04
Run 4	682.8	142.6	7650	8850	NA	0		6.78E-04

CONTAMINATION:

GC/MS analysis of organics present in the scrubber and makeup water indicated that the source of a significant fraction of POHC and PIC output rates was the scrubber water. For PICs, this was particularly evident for bromodichloromethane and dibromochloromethane.

COMMENTS:

Only brominated PICs were observed with bromoform in largest concentration. The percentage of PIC emissions (per unit POHC input) were <0.01% for all tests. PIC:POHC ratios were much less than unity. Particulate sampling indicated emissions were within federal regulations. No testing of particulate for organic material was conducted.

TWI INCINERATOR (UPSET CONDITIONS)

SITE DESCRIPTION:

Off-site facility that burns liquid and solid wastes. Incinerator design features a two-stage combustion chamber, a quench section, a Venturi scrubber and a packed scrubber. Primary combustion chamber can accept solid and liquid wastes through separate feed systems. Fuel oil and combustion air are admitted into both the primary and secondary chamber to maintain desired operating conditions. After exiting the secondary chamber, the gases are quenched and passed through a venturi scrubber for particulate and HCl removal. The gases then travel through a mist eliminator. Four runs were conducted for these tests burning three organic, aqueous, and solid waste streams under sub-optimal operating conditions.

RESIDENCE TIME (CALCULATED):

2.8-3.0 s (primary and secondary combustion chamber)

TEMPERATURE:

1120-1220°C (primary combustion chamber)
1120-1170°C (secondary combustion chamber)
79-84°C (prequench)
59-67°C (stack gas)

OXYGEN (DRY BASIS):

10.4-17.8% (continuous monitor, spread of readings for 4 runs)

CARBON DIOXIDE (DRY BASIS):

5.7-6.7% (continuous monitor, average readings for 4 runs)

WASTE FEED COMPOSITION:

Methylene chloride, methylene bromide, chloroform, carbon tetrachloride, 1,1,1-trichloroethane, trichloroethylene, tetrachloroethylene, toluene, benzene, chlorobenzene.

WASTE FEED RATES (KG/MIN):

	Run 6	Run 7	Run 8a	Run 8b	Average
Organic waste:	3.9	4.7	4.1	4.5	4.3
Aqueous waste:	7.6	9.1	4.7	6.4	6.95
Solid waste (high Btu ink sludge)	-	-	0.45	0.45	0.45

TWI INCINERATOR (UPSET CONDITIONS)

CALCULATED POHC FEED RATES (G/MIN) [1]:

Volatile POHCs:	Run 6	Run 7	Run 8a	Run 8b	Average
Methylene chloride	1.5 [2]	1.5 [2]	0.77 [2]	1 [2]	1.1925
Chloroform	0.94 [2]	0.66 [2]	0.41 [2]	0.54 [2]	0.6375
Methylene bromide	37	44	27	37	36.25
1,1,1-Trichloroethane	1.8 [2]	1.2 [2]	1.5 [2]	1.4 [2]	1.475
Carbon tetrachloride	52	29	49	50	45
Trichloroethylene	110	40	62	63	68.75
Benzene	290	350	300	330	317.5
Tetrachloroethylene	0.47 [2]	0.52 [2]	Not detected	0.5 [2]	0.4967
Toluene	980	1180	1020	1120	1075
Chlorobenzene	2	2.1	1.7	1.9	1.925
Total POHC Feedrate:	1475.71	1648.98	1462.38	1605.34	
Total ClPOHC Feedrate:	168.71	74.98	115.38	118.34	

Footnotes:

1. These input rates do not include any input of POHCs in the fuel oil.
2. The presence of POHCs in the fuel oil could significantly increase these input rates.

UNCORRECTED POHC EMISSION RATES (G/MIN):

Gas bags [1]:	Run 6	Run 7			Average
Methylene chloride	0.0076	0.0051			1.19250
Chloroform [2]	0.0035	0.000091			0.63750
Methylene bromide	0.0022	0.00049			0.00135
1,1,1-Trichloroethane	0.0012	0.0033			1.47500
Carbon tetrachloride	0.00083	0.00022			0.00053
Trichloroethylene	0.0083	0.0025			0.00540
Benzene	0.026	0.024			0.02500
Tetrachloroethylene	0.0011	0.00083			0.49670
Toluene	0.032	0.015			0.02350
Chlorobenzene	0.0044	0.0077			0.00605
Slow VOST [2]:					
Methylene chloride	0.0079	0.0078	0.0017	0.001	1.19250
Chloroform [2]	0.0086	0.0067	0.00068	0.00044	0.63750
Methylene bromide	0.0094	0.0047	0.000068	< 0.00006	0.00472
1,1,1-Trichloroethane	0.0022	0.0025	0.011	0.0018	1.47500
Carbon tetrachloride	0.0018	0.00067	0.0023	0.0026	0.00184
Trichloroethylene	0.012	0.0031	0.00065	0.00047	0.00406
Benzene	0.03	0.018	0.0027	0.00068	0.01285
Tetrachloroethylene	0.0017	0.001	0.00017	0.00018	0.49670
Toluene	0.095	0.047	0.0058	0.0017	0.03738
Chlorobenzene	0.008	0.0057	0.00053	0.000097	0.00358

TWI INCINERATOR (UPSET CONDITIONS)

UNCORRECTED VOLATILE PIC EMISSION RATES (G/MIN):

Gas Bags: [1]	Run 6	Run 7	Run 8a	Run 8b	Average
Bromochloromethane	0.00024	0.00058			0.00041
Bromodichloromethane	0.0019	< 0.0002			0.0019
Dibromochloromethane	0.0016	0.000083			0.0008415
Bromoform	0.0079	0.0046			0.00625
Slow VOST [1]:					
Bromochloromethane	0.00029	0.00053	< 0.00006	0.00077	0.00053
Bromodichloromethane	0.00098	0.00056	< 0.0001	< 0.0001	0.00077
Dibromochloromethane	0.0012	0.00053	< 0.0001	< 0.0001	0.000865
Bromoform	0.039	0.04	0.0028	< 0.0001	0.027266666667

Footnote (POHC and PIC output data):

1. Runs 6, 7, 8a, and 8b were short runs (20 min). Therefore, VOST results are for only one pair of traps for each run.
2. This compound may have been stripped from the scrubber water.

EMISSIONS ANALYSES:

Slow VOST:	POHC Emissions	Volatile PIC Emissions	CLPIC EMISSIONS	Total Emissions	PIC:POHC Ratio	% Emissions (per Waste Feed)	% PIC Emissions (per Waste Feed)	% PIC Emissions (per POHC Feed)
Run 6	0.176600	0.041470	0.0024700	0.21807	0.2348245	0.00189626087	0.0003606087	0.00281
Run 7	0.097170	0.041620	0.0016200	0.13879	0.4283215	0.001005724638	0.0003015942	0.00252
Run 8a	0.025598	0.002800	0.0000000	0.028398	0.1093835	0.000307005405	3.027027E-05	0.00019
Run 8b	0.008967	0.000770	NA	0.009737	0.0858704	8.57885463E-05	6.784141E-06	0.00005
	POHC Feedrate	CIPOHC Feedrate	Waste Feedrate			%CIPIC Emissions (per CIPOHC input)		
Run 6	1475.71	168.71	11500			0.001464050738		
Run 7	1648.98	74.98	13800			0.002160576154		
Run 8a	1462.38	115.38	9250			0		
Run 8b	1605.34	118.34	11350			NA		

Footnote:

1. The presence of POHCs in the fuel oil precludes accurate measurement of input rates.

CONTAMINATION:

Outflow and makeup water was not analyzed for organics. Comparison of emissions with waste feed do not present any clear evidence of contamination.

COMMENTS:

Only brominated PIC were observed with bromoform in largest concentration. PIC:POHC ratios in this study were much less than unity. Particulate sampling for these 4 runs was not conducted. Particulates were not tested for organic material. No discernible difference in organic emissions or PIC:POHC ratios was evident from comparison of optimum and upset condition measurements.

UPJOHN INCINERATOR

SITE DESCRIPTION:

This onsite incinerator is located in a chemical plant that is designed to burn gaseous and liquid production wastes. The unit consists of a small burner/ignition chamber section followed by a horizontal cylindrical thermal oxidizer chamber. Combustion gases leave the oxidizer and travel downward through a spray chamber and quench pot before entering a vertical scrubber/demister and exit via the exhaust stack. There is no particulate control device.

RESIDENCE TIME (CALCULATED):

5.2 s (thermal oxidizing chamber)

TEMPERATURE:

1116°C (thermal oxidizing chamber)
84-85°C (quench pot)

OXYGEN (DRY BASIS):

8.1-8.4% (continuous monitor, average readings for 3 runs)

CARBON DIOXIDE (DRY BASIS):

14.1-14.3% (continuous monitor, average readings for 3 runs)

WASTE FEED COMPOSITION:

Chloromethane, carbon tetrachloride, trichloroethylene, chlorobenzene, 1,2-dichlorobenzene, 1,3-dichlorobenzene, 1,4-dichlorobenzene, 1,2,4-trichlorobenzene, phosgene, aniline, phenylisocyanate, chlorophenyl isocyanate, bis(ethylhexyl)phthalate.

WASTE FEED RATES (KG/MIN):

	Run 2	Run 3	Run 4	Average
Liquid organic waste:	2.21	1.84	1.84	1.9633

CALCULATED POHC INPUT RATES (G/MIN):

Volatile POHCs:	Run 2	Run 3	Run 4	Average
Carbon tetrachloride	80	85	84	83.0000
Trichloroethylene	73	74	74	73.6667
Chlorobenzene	16	7.5	13	12.1667
Chloromethane	> 4.4	> 2.2	> 3.5	-

APPENDIX A, cont.

UPJOHN INCINERATOR

CALCULATED POHC FEED RATES (G/MIN):

Semivolatile POHCs				
1,2-Dichlorobenzene	4.6	4.2	5.7	4.8333
1,3-Dichlorobenzene	89	85	120	98.0000
1,4-Dichlorobenzene	120	110	150	126.6667
1,2,4-Trichlorobenzene	0.6	0.53	0.72	0.6167
bis(Ethylhexyl)phthalate	1.1	0.92	2.4	1.4733
Phenyl isocyanate	380	290	390	353.3333
Chlorophenyl isocyanate	51	39	51	47.0000
Aniline	-	26	35	30.5000
Phosgene	3950	4010	1560	3173.3333

UNCORRECTED POHC EMISSION RATES (G/MIN):

Volatile POHCs (gas bags):	Run 2	Run 3	Run 4	Average
Phosgene	0.058	0.28	0.3	0.212667
Carbon tetrachloride	0.0049	0.00058	0.0039	0.003127
Trichloroethylene	0.0017	0.0013	0.00032	0.001107
Chlorobenzene		0.011	0.0076	0.009300
Chloromethane	0.000064	0.00011	0.000086	0.000087
Volatile POHCs (VOST):				
Carbon tetrachloride [1]	0.00636667	0.00495	0.01053333	0.007283
Trichloroethylene [1]	0.0063	0.00705	0.00666667	0.006672
Chlorobenzene [2]	0.01136667	0.0078	0.00663333	0.008600
Chloromethane [2]	0.00049	0.00019	0.00035	0.000343
Semivolatile POHCs				
1,2-Dichlorobenzene [1]	0.0036	0.004	0.0039	0.0038
1,3-Dichlorobenzene [1]	0.00063	0.0054	0.00046	0.0022
1,4-Dichlorobenzene	0.0012	0.0058	0.0013	0.0028
1,2,4-Trichlorobenzene [1]	0.0021	0.0074	0.0018	0.0038
bis(Ethylhexyl)phthalate [1]	0.00025	0.00049	0.00042	0.0004
Phenyl isocyanate [2]	< 0.0003	< 0.0003	< 0.0003	< 0.0003
Chlorophenyl isocyanate	Not reported	Not reported	Not reported	
Aniline [2]	< 0.0003	< 0.0003	< 0.0003	< 0.0003

APPENDIX A, cont

UPJOHN INCINERATOR

UNCORRECTED VOLATILE PIC EMISSION RATES (G/MIN):

		Run 2	Run 3	Run 4	Average
Gas bags:					
	Chloroform [1]	0.15	0.034	0.017	0.067000
	Benzene [1]	0.0028	0.012	0.0019	0.005567
	Tetrachloroethylene [1]	0.00029	0.00015	0.000097	0.000179
	Toluene [1]	0.002	0.00069	0.00037	0.001020
	Methylene chloride [2]	0.0013	0.0012	0.0023	0.001600
	Methyl ethyl ketone [2]	0.00031	0.000095	0.00021	0.000205
	Bromodichloromethane [2]	0.014	0.0023	0.00077	0.005690
	Dibromochloromethane [2]	0.0017	0.00016	0.000065	0.000642
VOST (1st pair):					
	Chloroform [1]	0.27	0.023	0.014	0.102333
	Benzene [1]	0.0035	0.0058	0.0075	0.005600
	Tetrachloroethylene [1]	0.00017	0.00016	0.00033	0.000220
	Toluene [1]	0.0042	0.0019	0.0046	0.003567
	Methylene chloride [2]	0.00088	0.0003	0.0008	0.000660
	Methyl ethyl ketone [2]	0.000071	0.00017	0.00015	0.000130
	Bromodichloromethane [2]	0.0046	0.0017	0.0011	0.002467
	Dibromochloromethane [2]	0.0025	0.00079	0.0007	0.001330
VOST (average of 2 or more pairs):					
	Chloroform [1]	0.19066667	0.022	0.01566667	0.076111
	Benzene [1]	0.00216667	0.0058	0.00356667	0.003844
	Tetrachloroethylene [1]	0.000127	0.000135	0.00019	0.000151
	Toluene [1]	0.0047	0.00165	0.00227	0.002873
	Methylene chloride [2]	0.00093	0.00041	0.00097667	0.000772
	Methyl ethyl ketone [2]	0.000064	0.00026	0.00022	0.000181
	Bromodichloromethane [2]	0.00393333	0.00155	0.0011	0.002194
	Dibromochloromethane [2]	0.0021	0.000595	0.00048	0.001058

Footnote:

1. Quantified relative to authentic calibration standard.
2. Semiquantified relative to perfluorobenzene internal standard.

APPENDIX A, cont.

UPJOHN INCINERATOR

UNCORRECTED SEMIVOLATILE PIC EMISSION RATES (G/MIN):

	Run 2	Run 3	Run 4	Average
Phenol	0.00048	0.00016	< 0.00004	0.000320
Naphthalene	0.000069	0.00038	0.00035	0.000266
2,6-Toluene diisocyanate	< 0.0002	0.0002	< 0.0002	0.000200
Diethyl phthalate	0.0005	0.00036	0.00028	0.000380
Hexachlorobenzene	0.000032	< 0.00002	0.000016	0.000024
o-Chlorophenol	0.00016	0.0012	0.000076	0.000479
2,4,6-Trichlorophenol	0.005	0.0067	0.0059	0.005867
Pentachlorophenol	0.00045	0.00029	0.00028	0.000340
o-Nitrophenol	0.00053	0.0023	0.0012	0.001343

EMISSION ANALYSES:

	POHC Emissions	PIC Emissions	PIC:POHC Ratio	% PIC Emissions (per POHC input)	% CIPIC Emissions (per CIPOHC input)
Gas bags+ semivolatiles:					
Run 2	0.072444	0.179621	2.479446	0.003769	0.003987
Run 3	0.316080	0.062185	0.196738	0.001314	0.001051
Run 4	0.319786	0.030814	0.096358	0.001240	0.001318
VOST (averages) + semivolatiles:					
Run 2	0.032303	0.416596	12.896388	0.008742	0.004689
Run 3	0.043080	0.076390	1.773213	0.001614	0.000751
Run 4	0.032063	0.057042	1.779041	0.002295	0.001228

CONTAMINATION:

Outflow and makeup water was analyzed for POHCs with chlorobenzene and bis(ethylhexyl) phthalate detected. Analysis for PICs in scrubber makeup water was not performed. Brominated emissions inconsistent with waste feed composition; these compounds are likely produced from one of the following:

1. Stripping of volatile compounds from scrubber water
2. PICs from brominated compounds in waste whose concentrations are less than 100 ug/g.

ZAPATA INCINERATOR

SITE DESCRIPTION:

This is an on-site incinerator designed to burn varnish and lacquer wastes from an industrial process. The unit includes a pyrolytic chamber and a thermal reactor. There is no control device for particulates or HCl. All waste was fed from a single waste feed tank. The incinerator operated normally during the four test runs. However, the continuous monitoring sampling probes were moved after run 1 to a new sampling port 10.5 ft downstream in the stack after run 1 due to wide fluctuations in CO and TUHC concentrations. This was believed to be due to the flame extending from the secondary chamber.

RESIDENCE TIME (CALCULATED):

0.063-0.069 s (pyrolysis + combustion chamber)

TEMPERATURE:

670-737°C (pyrolysis chamber)
844-904°C (combustion chamber)
611-679°C (stack)

OXYGEN (DRY BASIS):

11.8-12.0% (continuous monitor, average readings for runs 2, 3 and 4)

CARBON DIOXIDE (DRY BASIS):

No analysis was conducted.

WASTE FEED COMPOSITION:

Methylene chloride, carbon tetrachloride, trichloroethylene, toluene, chlorobenzene

WASTE FEED RATES (KG/MIN):

Run 1	Run 2	Run 3	Run 4	Average
0.66	0.76	0.78	0.77	0.7425

CALCULATED POHC FEED RATES (G/MIN):

	Run 1	Run 2	Run 3	Run 4	Average
Methylene chloride	0.04	0.16	< 0.008	< 0.02	0.1
Carbon tetrachloride	8.7	9.9	11	11	10.15
Trichloroethylene	8	9.2	9.4	9.2	8.95
Toluene	8	4	1.1	12	6.275
Chlorobenzene	601	7	7.4	704	329.85

ZAPATA INCINERATOR

UNCORRECTED POHC EMISSION RATES (G/MIN):

Gas bags:	Run 1	Run 2	Run 3	Run 4	Average
Methylene chloride	0.00016	0.00032	0.00011	0.00011	0.0001750
Carbon tetrachloride	0.0024	0.00041	0.0068	0.00031	0.0024800
Trichloroethylene	0.0017	0.0012	0.0019	0.00048	0.0013200
Toluene	0.00038	0.0006	0.0004	0.00053	0.0004775
Chlorobenzene	0.00028	0.00026	0.00066	0.00013	0.0003325

UNCORRECTED POHC EMISSION RATES (G/MIN):

VOST (1st pair):	Run 2	Run 3	Average
Methylene chloride	0.00026	0.0000580	0.0001590
Carbon tetrachloride	0.0001300	0.00008	0.0001050
Trichloroethylene	0.00044	0.00026	0.0003500
Toluene	0.001	0.0001000	0.0005500
Chlorobenzene	0.00091	0.000042	0.0004760
VOST (average values):	Run 2	Run 3	Average
Methylene chloride	0.0001675	0.0000873	0.0001274
Carbon tetrachloride	0.0000887	0.00011	0.0000993
Trichloroethylene	0.000203	0.000151	0.0001770
Toluene	0.00035567	0.0000743	0.0002150
Chlorobenzene	0.00033567	0.0002	0.0002678

UNCORRECTED VOLATILE PIC EMISSION RATES (G/MIN):

Gas Bags:	Run1	Run 2	Run 3	Run 4	Average
Chloroform	0.000036	0.000035	0.000035	0.000031	0.00003425
1,1,1-Trichloroethane	0.000038	0.000052	0.000027	0.000026	0.00003575
Benzene	0.00072	0.0013	0.00016	0.00016	0.000585
Tetrachloroethylene	0.000042	0.000022	0.000022	0.000022	0.000027
VOST (1st pair):					
Chloroform	No analysis	0.000034	0.000071	No analysis	0.0000525
1,1,1-Trichloroethane	No analysis	0.000009	0.000016	No analysis	0.0000125
Benzene	No analysis	0.0024	0.00018	No analysis	0.00129
Tetrachloroethylene	No analysis	0.000019	0.000021	No analysis	0.00002
VOST (average):					
Chloroform	No analysis	0.0000560	0.0000623	No analysis	0.0000592
1,1,1-Trichloroethane	No analysis	0.0000120	0.0000203	No analysis	0.0000162
Benzene	No analysis	0.0008607	0.0002667	No analysis	0.0005637
Tetrachloroethylene	No analysis	0.0000137	0.0000200	No analysis	0.0000168

APPENDIX A, cont.

ZAPATA INCINERATOR

EMISSION ANALYSES:

	POHC Emissions	Volatile PIC Emissions	PIC:POHC Ratio	% PIC Emissions (per POHC input)	% CIPIC Emissions (per CIPOHC input)
Gas bags:					
Run 1	0.0049200	0.0008360	0.1699187	0.000134	0.000019
Run 2	0.0027900	0.0014090	0.5050179	0.004656	0.000415
Run 3	0.0098700	0.0002440	0.0247214	0.000844	0.000302
Run 4	0.0015600	0.0002390	0.1532051	0.000032	0.000011
VOST:					
Run 2	0.0011505	0.0009423	0.8190352	0.003114	0.000311
Run 3	0.0006227	0.0003693	0.5931478	0.001278	0.000369

CONTAMINATION:

Outflow and makeup water was not analyzed for emissions. There was no evidence of contamination in the reported emissions data.

COMMENTS:

Benzene was the major PIC observed from these tests. % PIC emissions (per unit POHC input) were < 0.01. PIC:POHC ratios were less than unity. It should also be noted that although the incinerator did not employ APCDs for HCl and particulate removal, particulate emissions were much less than the federal regulation. Particulates were not tested for organic material. Semivolatile PICs were not measured.

SITE D - ACUREX

SITE DESCRIPTION:

The industrial boiler tested at site D was a balanced draft B & W field-erected watertube boiler with a rated steam flowrate of 11.4 kg/s of saturated steam at 1.8 MPa. The unit is currently equipped with four conventional single-register oil- and gas-fired B & W burners arranged in a two-by-two matrix. The boiler has essentially no particulate control device since a multiclone, which was part of the original unit configuration for particulate collection during coal-burning, was removed upon conversion to oil and gas burning. Incineration efficiency of two solvent waste streams containing hazardous chlorinated compounds was investigated in this test program.

BULK FURNACE RESIDENCE TIME (CALCULATED):

1.1-1.3 s

BULK FURNACE TEMPERATURE (CALCULATED):

1370-1430°C

OXYGEN (DRY BASIS):

5.1-6.2% (spread of 6 test measurements)

WASTE FEED COMPOSITION (POHCs ONLY):

Tetrachloroethylene, toluene, bis(2-chloroethyl)ether

CALCULATED POHC FEED RATES (G/S):

	PCE [1]	bis(2-Chloroethyl)ether	Toluene
Test 2	77.9		
Test 3	33.6		
Test 4	19.6		
Test 5		7.5	180
Test 6		7.5	180
Test 7		7.5	180

Footnote:

1. PCE: Tetrachloroethylene.

SITE D - ACUREX

CORRECTED AVERAGE VOLATILE PIC EMISSION RATES (UG/S):

	Benzene	Toluene [1]	PCE [1]	Carbon tetrachloride	1,1,2-TCA [2]
Test 2	680	750		200	110
Test 3	570	430		270	150
Test 4	220	740			
Test 5			590		
Test 6	50		600	94	47
Test 7	150		50		0

	DCM [2]	Chloroform	TCE [2]	1,1,1-TCA [3]	1,2-DCA [2]	1,1-DCE [2]
Test 2	2100	360	30	260	64	360
Test 3	1600	290	12	160	50	92
Test 4	6000	120	25	140		350
Test 5	1800	410	15	110	26	130
Test 6	860	160	28	200		110
Test 7		210		46		

Footnote:

1. Data refers to toluene emissions as a PIC for tests 2-4 and PCE as a PIC for tests 5-7.
2. 1,1,2-TCA = 1,1,2-Trichloroethane; DCM = Dichloromethane; TCE = Trichloroethylene; 1,1,1-TCA = 1,1,1-Trichloroethane; 1,2-DCA = 1,2-Dichloroethane; 1,1-DCE = 1,1-Dichloroethylene.

CORRECTED SEMIVOLATILE PIC EMISSION RATES (UG/S):

	bis(2-Chloroethyl) ether	Phenol	1,4-Dichlorobenzene	Naphthalene	2,4-DCP [1]
Test 2	5.4	8.1	6.1	13	5.3
Test 3		8		6.7	
Test 4	7.4	16.3	9.7	13	
Test 5		4.9			
Test 6	4.2	7.1		7.9	
Test 7	11	8.6		7.9	

	2,4,6-TCP [1]	1,3-Dichlorobenzene	Benzo(a)anthracene	1-Chlorophenol
Test 2	16			
Test 3		12		
Test 4		7.3		
Test 5				
Test 6			3.1	
Test 7		6.1		8.9

Footnote:

1. 2,4-DCP = 2,4-Dichlorophenol; 2,4,6-TCP = 2,4,6-Trichlorophenol.

SITE D - ACUREX

EMISSIONS ANALYSIS:

	Total Emissions	POHC Emissions	PIC Emissions	CLPIC Emissions	PIC:POHC Ratio
Test 1	2047.6	NA	1746.2		N/A
Test 2	6129.9	880	4967.9	3516.8	5.65
Test 3	4620.2	630	3650.7	2636	5.79
Test 4	8765.7	860	7648.7	6659.4	8.89
Test 5	3304.9	8	3085.9	3081	385.74
Test 6	3157.3	724	2171.3	2103.2	3.00
Test 7	2047.8	1307	498.5	332	0.38

	% PIC Emissions (per POHC input)	% CLPIC Emissions (per CLPOHC input)	% PIC Emissions (per waste input)
Test 2	0.0064	0.0045	0.0022
Test 3	0.0109	0.0078	0.0016
Test 4	0.0390	0.0340	0.0035
Test 5	0.0016	0.0411	0.0019
Test 6	0.0012	0.0280	0.0013
Test 7	0.0003	0.0044	0.0003

	Waste Feedrate	CLWaste Feedrate	% DCM Emissions (per CLPOHC input)	1,1-DCE Emissions (per CLPOHC input)
Test 2	222.8160	11.1408	0.002696	0.000462
Test 3	231.2560	11.5628	0.0048	0.000274
Test 4	216.9080	10.8454	0.0800	0.0047
Test 5	165.6820	10.76933	0.0240	0.0017
Test 6	165.6820	10.76933	0.0115	0.0015
Test 7	170.1120	11.05728		

	Total Feedrate	Total Emissions	% PIC Emissions (per fuel/waste input)	% CIPIC Emissions (per fuel/waste input)	% Emissions (per fuel/waste input)
Test 1	504.0	2047.6	0.000346	0.000000	0.000406
Test 2	615.6	6129.9	0.000807	0.000571	0.000996
Test 3	608.1	4620.2	0.000600	0.000434	0.000760
Test 4	640.9	8765.7	0.001193	0.001039	0.001368
Test 5	322.5	3304.9	0.000957	0.000955	0.001025
Test 6	319.3	3157.3	0.000680	0.000659	0.000989
Test 7	318.9	2047.8	0.000156	0.000104	0.000642

SITE D - ACUREX

CONTAMINATION:

None evident.

TARGET COMPOUNDS FOR EMISSIONS ANALYSIS:

Volatiles:

Chloromethane
Dichloroform
Chloroform
Tetrachloromethane
Chloroethane
1,1-Dichloroethane
1,2-Dichloroethane
1,1,1-Trichloroethane
1,1,2-Trichloroethane
1,1,1,2-Tetrachloroethane
1,1,2,2-Tetrachloroethane
1,2-Dichloropropane
Hexachlorocyclohexane
Chloroethylene
1,1-Dichloroethylene
1,2-Dichloroethylene
Trichloroethylene
Tetrachloroethylene
Allyl chloride
1,3-Dichloropropene
Chloroprene

Ethylene oxide
Propylene oxide

Epichlorohydrin
2-Chloroethyl vinyl ether

Acetaldehyde
Acrolein

Acrylonitrile

Benzene
Toluene
Ethyl benzene
o-Xylene
m-Xylene
p-Xylene

Chlorobenzene

TARGET COMPOUNDS FOR PIC ANALYSIS:

Semivolatiles:

Acid Compounds

2,4,6-Trichlorophenol
p-Chloro-m-cresol
2-Chlorophenol
2,4-Dichlorophenol
2,4-dimethylphenol

2-Nitrophenol
4-Nitrophenol
2,4-Dinitrophenol
4,6-Dinitrophenol
Pentachlorophenol
Phenol

SITE D - ACUREX

TARGET COMPOUNDS FOR PIC ANALYSIS:

Semivolatiles: **Base Neutral Compounds**

1,2,4-Trichlorobenzene
1,2-Dichlorobenzene
1,2-Diphenylhydrazine
(as azobenzene)
1,3-Dichlorobenzene
1,4-Dichlorobenzene
2,4-Dinitrotoluene
2,6-Dinitrotoluene
2-Chloronaphthalene
3,3'-Dichlorobenzidine
3-Methyl cholanthrene
4-Bromophenyl phenyl ether
4-Chlorophenyl phenyl ether
7,12-Dimethyl benz(a)anthracene
N-Nitrosodi-n-propylamine
N-Nitrosodimethylamine
N-Nitrosodiphenylamine
Acenaphthene
Acenaphthylene
Anthracene
Benzo(ghi)perylene
Benzidine
Benzo(b)fluoranthene
Benzo(k)fluoranthene
Benzo(a)anthracene
Benzo(a)pyrene

Benzo(c)phenanthrene
bis(2-Chloroethoxy)methane
bis(2-Chloroethyl)ether
bis(2-Chloroisopropyl)ether
bis(2-Ethylhexyl)phthalate
Butyl benzyl phthalate
Chrysene
Di-n-butyl phthalate
Di-n-octyl phthalate
Dibenzo(a,h)anthracene
Dibenzo(c,g)carbazole
Diethyl phthalate
Dimethyl phthalate
Fluoroanthene
Fluorene
Hexachlorobenzene
Hexachlorobutadiene
Hexachlorocyclopentadiene
Hexachloroethane
Indeno(1,2,3-cd)pyrene
Isophorone
Naphthalene
Nitrobenzene
Perylene
Phenanthrene
Pyrene

COMMENTS:

Dichloromethane, toluene, benzene, chloroform, tetrachloroethylene, carbon tetrachloride, 1,1,1-trichloroethane, 1,1,2-trichloroethane, and 1,1-dichloroethylene were the major PICs observed (excluding bis-2-ethylhexylphthalate). The percentage of PIC emissions (per unit POHC input) were ≥0.01% in only 2 of the 7 tests. PIC:POHC ratios in this study were consistently larger than unity with test 5 yielding a value of 386. Semivolatile emissions were much less than volatile emissions. Particulate sampling of the stack was not conducted. Sampling for PCDDs and PCDFs was not conducted. The PIC emission rate in test 7 was much lower than other tests at this site or as compared to similar data for other boilers tested.

SITE E - ACUREX

SITE DESCRIPTION:

The industrial boiler tested at site E was a forced draft CE type 30-a-12 packaged watertube boiler with a maximum capacity of 13.9 kg/s of saturated steam at 2.94 MPa. The unit is equipped with one dual-air-register COEN burner. The boiler is not equipped with a particulate control device. Incineration efficiency of three organic waste streams was investigated in this test program when cofired with either no. 6 fuel oil or natural gas.

BULK FURNACE RESIDENCE TIME (CALCULATED):

0.8-1.1 s (gas-fired)
0.5-1.0 s (oil-fired)

BULK FURNACE TEMPERATURE (CALCULATED):

1480-1590°C (gas-fired)
1480-1590°C (oil-fired)

OXYGEN (DRY BASIS):

5.5-7.4% (spread of 8 test measurements)

WASTE FEED COMPOSITION (POHCs ONLY):

Methyl methacrylate, carbon tetrachloride, toluene, trichloroethylene

CALCULATED POHC FEED RATES (G/S):

	Methyl methacrylate	Carbon tetrachloride	Toluene	TCE [1]	Chlorobenzene
Test 2	6.67				
Test 3	8.87	6.55		6.79	3.9
Test 4	8.6	7.48		7.66	4.14
Test 5	12.45	7.29		7.24	4.03
Test 6	12.1	7.62		7.36	4.69
Test 7	11.8	8.34		7.74	4.77
Test 8	9.44	6.79		6.03	3.66
Test 9	27.8		180		

Footnote:

1. TCE: Trichloroethylene

APPENDIX B. cont

SITE E - ACUREX

CORRECTED AVERAGE VOLATILE PIC EMISSION RATES (UG/S):

	1,1,1-TCA [1]	PCE [1]	1,1,2,2-TCA [1]	Toluene	Benzene	Chloroform
Test 2	280	1050	130	3350	76	34
Test 3		500		1300	180	
Test 4	52	630	70	2000	200	45
Test 5	200	800		1780	480	73
Test 6	170	870		2000	410	200
Test 7	800	9500	180	12000	3600	21000
Test 8	77	2200		4500	910	5800
Test 9	320	2000			1000	4200
	Chloromethane	Dichloromethane				
Test 2						
Test 3		50000				
Test 4						
Test 5						
Test 6						
Test 7						
Test 8						
Test 9	68					

Footnote:

1. 1,1,1-TCA = 1,1,1-Trichloroethane; 1,1,2,2-TCA = 1,1,2,2-Tetrachloroethane; PCE = Tetrachloroethylene.

CORRECTED SEMIVOLATILE PIC EMISSION RATES (UG/S):

	Dibutyl Phthalate	Diethyl Phthalate	bis-2-ethylhexylphthalate		Fluoranthene	Phenol
Test 2	15	4.2			2.1	13
Test 3						
Test 4	10				3	14
Test 5		5	120			
Test 6	2	3.9				
Test 7	18		8			10
Test 8			26			1.4
Test 9			1500			
	Chlorobenzene	Acenapthalene	Naphthalene	Di-n-octyl phthalate		Butylbenzylphthalate
Test 2	3					
Test 3	190					
Test 4		2	40			1.7
Test 5				10		
Test 6			5.9	6.9		
Test 7						
Test 8						
Test 9			34	85		

SITE E - ACUREX

EMISSION ANALYSES:

	POHC EMISSIONS	PIC Emissions (except phthalates)	Total Emissions	CLPIC Emissions	PIC:POHC Ratio
Test 1		4930	5175		NA
Test 2	220.0	4938.1	5638.2	1497.0	22.4
Test 3	4359.0	52170.0	57273.0	50690.0	12.0
Test 4	1458.0	3056.0	6059.0	797.0	2.1
Test 5	472.0	3333.0	5258.0	1073.0	7.1
Test 6	896.0	3655.9	6008.9	1240.0	4.1
Test 7	1446.0	47090.0	68696.0	31480.0	32.6
Test 8	774.7	13488.4	28264.4	8043.0	17.4
Test 9	5530.0	7622.0	18679.0	6622.0	1.4

	Total Feedrate	Waste Feedrate	CLPOHC Feedrate	% PIC Emissions (per waste input)	% PIC Emissions (per POHC input)
Test 1	571.7	0.0	0.0	NA	NA
Test 2	551.7	159.7	0.0	0.0031	0.0740
Test 3	511.4	193.3	17.2	0.0270	0.1998
Test 4	521.0	229.8	19.3	0.0013	0.0110
Test 5	517.1	221.0	18.6	0.0015	0.0107
Test 6	391.3	230.7	19.7	0.0016	0.0115
Test 7	717.4	220.1	20.9	0.0214	0.1442
Test 8	441.9	224.6	16.5	0.0060	0.0520
Test 9	329.0	203.7	0.0	0.0037	0.0037

	% CHCL3 Emissions (per CLWaste input)	% PCE Emissions (per CLWaste input)	% PIC Emissions (per fuel/waste input)
Test 1	NA	NA	0.000862
Test 2	NA	NA	0.000895
Test 3	0.0000	0.0061	0.010201
Test 4	0.0002	0.0026	0.000587
Test 5	0.0004	0.0034	0.000645
Test 6	0.0010	0.0041	0.000934
Test 7	0.1007	0.0042	0.006564
Test 8	0.0352	0.0576	0.003052
Test 9	NA	NA	0.002317

CONTAMINATION:

No APCDs were employed.

SITE E - ACUREX

TARGET COMPOUNDS FOR PIC ANALYSIS:

See Site D.

COMMENTS:

Toluene, benzene, chloroform, tetrachloroethylene, carbon tetrachloride, and 1,1,1-trichloroethane were the major PICs observed (excluding bis-2-ethylhexylphthalate). The percentage of PIC emissions (per POHC input) was ≥0.01% for 6 of 8 tests. PIC:POHC ratios in this study ranged from 0.5 to 33.0, with values typically much greater than unity. Semivolatile emissions were much less than volatile emissions. Particulate sampling of the stack was not conducted. Sampling for PCDDs and PCDFs was not conducted. PIC emission rates in test 8 w higher than other tests or as compared to similar data for other boilers tested.

SITE F - ACUREX

SITE DESCRIPTION:

The industrial boiler tested at site F was a balanced draft B&W integral furnace F-18/48 watertube boiler with a rated steam capacity of 7.6 kg/s of saturated steam at 1.4 MPa. The unit is equipped with two B&W circular burners capable of burning no. 6 fuel oil, no. 2 fuel oil, natural gas, or propane arranged in two levels. No APCDs were employed. Incineration efficiency of a chlorinated hydrocarbon spiked purge thinner was evaluated.

BULK FURNACE RESIDENCE TIME (CALCULATED):

2.0 s

BULK FURNACE TEMPERATURE (CALCULATED):

1370°C

OXYGEN (DRY BASIS):

8.0-8.5% (spread of 3 test measurements)

WASTE FEED COMPOSITION (POHCs ONLY):

Carbon tetrachloride, trichloroethylene, toluene, chlorobenzene

CALCULATED POHC FEED RATES (G/S):

	Carbon tetrachloride	Trichloroethene	Toluene	Chlorobenzene
Test 2	0.547	0.205	0.0339	0.268
Test 3	1.03	1.69	0.194	0.41
Test 4	0.837	1.4	0.0994	0.131

CORRECTED AVERAGE VOLATILE PIC EMISSION RATES (UG/S):

	PCE [1]	DCM [1]	1,2-DCA [1]	1,2-DCP [1]	1,1,1-TCA [1]	Benzene	
Test 2	1.9	9.3	13	3.3	83	1300	
Test 3	3.3	6830	82.6	1.2	926	349	
Test 4	1.4	496	5.8	1.5	20	193	
	1,1,2,2-TCA [1]	t-1,2-DCE [1]	Chloromethane	Chloroform	t-1,3-DCP [1]	Chloroethane	
Test 2	44.5	23.2	810	534	0.3	19.3	
Test 3	5	26.5	1481	6630	0.4	26.0	
Test 4		0.76	282	16.3		7.8	
	Bromoform	1,1-DCE [1]	Vinyl chloride	Trichlorofluoromethane		Dichlorobromomethane	c-1,3-DCP
Test 2	22		43.1	4640		2.3	0.30
Test 3			53	947		484	0.40
Test 4		2	5.5	107			

Footnote:

1. PCE = Tetrachloroethylene; DCM = Dichloromethane; 1,2-DCP = 1,2-Dichloropropane; 1,1,1-TCA = 1,1,1-Trichloroethane; 1,1,2,2-TCA = 1,1,2,2-Tetrachloroethane; t-1,2-DEC = trans-1,2-Dichloroethylene; t-1,3-DCP = trans-1,3-Dichloropropene; 1,1-DCE = 1,1-Dichloroethylene; c-1,3-DCP = cis-1,3-Dichloropropene.

SITE F - ACUREX

CORRECTED SEMIVOLATILE PIC EMISSION RATES (UG/S):

	Dibutyl Phthalate	Diethyl Phthalate	bis-2-ethylhexylphthalate	2,4-DMP [1]	Phenol
Test 2	2.9	2.9	ND	ND	2.3
Test 3	ND	1.1	58	ND	1.6
Test 4	ND	1	ND	33	8.1
	bis(2-chloroisopropyl) ether		Naphthalene		
Test 2	ND		4		
Test 3	ND		3.2		
Test 4	68		6.3		1.7

Footnote:

1. 2,4-DMP = 2,4-Dimethylphenol.

EMISSIONS ANALYSES:

	POHC Emissions	PIC Emissions (less phthalates)	CIPIC EMISSIONS	Total Emissions	% PIC Emissions (per waste input)	% PIC Emissions (per POHC input)	PIC:POHC Ratio
Test 1	N/A	11127.6	9745.8	11348.1			
Test 2	403	7553.5	6227.5	8780.3	0.028961	0.716719	18.74
Test 3	820	17848.6	17496.4	18105.3	0.054101	0.536961	21.77
Test 4	57	1246.36	946.06	1675.56	0.004357	0.050513	21.87
	Total Feedrate	CLPOHC Feedrate	Waste Feedrate		% Total Emissions (per fuel/waste input)	% PIC Emissions (per fuel/waste input)	
Test 1	200.8				0.005651	0.005542	
Test 2	198.082	1.02	26.082		0.004433	0.003813	
Test 3	208.991	3.13	32.991		0.008663	0.008540	
Test 4	196.608	2.368	28.608		0.000852	0.000634	
	% CLPIC Emissions (per CLPOHC input)		% DCM Emissions (per CLPOHC input)		% Bz Emissions (per fuel/waste input)	% CIPIC Emissions (per fuel/waste input)	
Test 1	NA		NA		NA	0.0049	
Test 2	0.6105		0.0009		0.0007	0.0031	
Test 3	0.5590		0.2182		0.0002	0.0084	
Test 4	0.0400		0.0209		0.0001	0.0005	

CONTAMINATION:

No APCDs were employed.

TARGET COMPOUNDS FOR PIC ANALYSIS:

See Site D.

SITE F - ACUREX

COMMENTS:

Chloromethane, dichloromethane, chloroform, trichlorofluoromethane, benzene, and 1,1,1-trichloroethane were the major PICs observed. The percentage of PIC emissions (per unit POHC feed rate) was >0.01% for all three tests. For two of the three tests, values approached 1%. PIC:POHC ratios in this study ranged from 20.0 to 30.0. Semivolatile emissions were much less than volatile emissions. Particulate sampling of the stack and analysis for PCDF and PCDD emissions were not conducted. Substantial levels of fluorinated and brominated PICs were detected. Trace analysis of the waste streams was not conducted to determine if any low level brominated or fluorinated compounds were present. PIC emission rates in test 4

SITE G - ACUREX

SITE DESCRIPTION:

The industrial boiler tested at site G was a Johnston modified three-pass wetback scotch marine packaged firetube boiler with amaximum heat input capacity of 14.7 MW and a maximum saturated steam pressure of 1.75 MPa. The boiler was retrofitted with two patented scrubber columns to recover halogen acids. The modified boiler is capable of firing natural gas and halogenated hydrocarbons in both liquid and gaseous form. Incineration efficiency of a chlorinated hydrocarbon spiked paint thinner waste was evaluated in this test program. Waste was not cofired with primary fuel.

BULK FURNACE RESIDENCE TIME (CALCULATED):

0.3-0.5 s

BULK FURNACE TEMPERATURE:

1300-1400°C

OXYGEN (DRY BASIS):

8.6-8.7% (spread of 3 test measurements)

WASTE FEED COMPOSITION (POHCs ONLY):

Carbon tetrachloride, epichlorohydrin, bis(2-Chloroisopropyl) ether

CALCULATED POHC FEED RATES (G/S):

	Carbon tetrachloride	Epichlorohydrin	bis(2-Chloroethyl)ether
Test 1	7.74	40.4	107
Test 2	9.48	40.4	107
Test 3	10.4	40.4	107

SITE G - ACUREX

CORRECTED VOLATILE PIC EMISSION RATES (UG/S):

	Chloroform	DCM [1]	Chloromethane	Chlorobenzene	1,2-DCA [1]	PCE [1]
Test 1	6000	180	10	390	15	
Test 2	2300	250	750	140	2400	750
Test 3	280			12	100	270
	1,1-DCE [1]	1,2-DCP [1]	Benzene	Toluene	Chloroethene	Chloroethane
Test 1	0.66			4.6		0.77
Test 2	0.65	80	17	28	1.2	2
Test 3	2.1	32		110	0.35	2.3
	DCBM [1]					
Test 1	660					
Test 2	170					
Test 3	160					

Footnote:

1. DCM = Dichloromethane; 1,2-DCA = 1,2-Dichloroethane; PCE = Tetrachloroethylene; 1,1,-DCE = 1,1,-Dichloroethylene; 1,2-DCP = 1,2-Dichloropropane; DCMBM = Dichlorobromomethane.

CORRECTED SEMIVOLATILE PIC EMISSION RATES (UG/S):

	bis(2-Chloroisopropyl) ether	2,4-DMP [1]	Naphthalene	2,4,6-TCP [1]	Fluorene
Test 1		1.9	2.2	1.8	0.82
Test 2	1.2		1.6	15	
Test 3			1.5	8	
	Dimethyl phthalate	HCB [1]	Butyl benzyl phthalate		
Test 1	7.7	6	2.1		
Test 2	1.8	4.2	3.1		
Test 3	4	5.9	0.76		
	bis(2-ethylhexyl) phthalate	Dibutyl phthalate		Phenol	
Test 1	22	6			
Test 2	32			2	
Test 3	11	1.8			

Footnote:

1. 2,4-DMP = 2,4-Dimethylphenol; 2,4,6-TCP = 2,4,6-Trichlorophenol; HCB = Hexachlorobenzene.

SITE G - ACUREX

EMISSIONS ANALYSES:

	POHC Emissions	CLPIC Emissions	PIC Emissions (less phthalates)	Total Emissions	% Total Emissions (per fuel/waste input)	% PIC EMISSIONS (per POHC input)	PIC:POHC Ratio
Test 1	93.00	7266.95	7273.75	79425.95	0.0321	0.0047	78.21
Test 2	460.00	6864.25	6912.85	7623.15	0.0031	0.0044	15.03
Test 3	110.00	872.65	984.15	1729.15	0.0007	0.0006	8.95
	Waste Feedrate	CLPOHC Feedrate	% PIC Emissions (per waste input)		% CLPIC Emissions (per CLPOHC input)	% CLPIC Emissions (per CLwaste input)	
Test 1	247.32	155.14	0.0029		0.0047	0.0030	
Test 2	248.184	156.88	0.0028		0.0044	0.0028	
Test 3	245.03	157.8	0.0004		0.0006	0.0004	
	% CHCL3 Emissions (per CLPOHC input)		% CHCL3 Emissions (per CLWASTE input)		% CLBz Emissions (per CLPOHC input)	% CLBz Emissions (per CLWASTE input)	
Test 1	0.00386747		2.46E-03		2.51E-04	1.60E-04	
Test 2	0.00146609		9.40E-04		8.92E-05	5.72E-05	
Test 3	0.00017744		1.16E-04		7.60E-06	4.97E-06	

CONTAMINATION:

Analysis of mass flowrates of organics in liquid discharge streams indicated significant quantities of DCM, chloroform, DCBM, and CDBM. Thus, in this study, contribution of makeup water DCM, chloroform, and DCBM emissions to flue gas measurements is probable.

TARGET COMPOUNDS FOR PIC ANALYSIS:

See Site D.

COMMENTS:

Chloromethane, dichloromethane, chloroform, dichlorobromomethane, 1,2-dichloroethane, tetrachloroethylene, chlorobenzene, and toluene were the major PICs observed. PIC:POHC ratios in this study ranged from 9.0 to 78.0. However, the percentage of PIC emissions (per unit POHC feed rate) was <0.01% for all tests. Semivolatile emissions were much less than volatile emissions. Particulate sampling of the stack was not conducted. Sampling for PCDDs and PCDFs was not conducted. Substantial levels of brominated PICs were detected. Trace analysis of the waste streams was not conducted to determine if any low level brominated compounds were present. Analysis of mass flowrates of organics in liquid discharge streams indicated significant quantities of DCM, chloroform, DCBM, and CDBM. Thus, in this study, contribution of makeup water DCM, chloroform, and DCBM emissions to flue gas measurements is probable. PIC emission rates in test 3 were much lower than other tests or as compared to similar data for other boilers tested.

SITE H - ACUREX

SITE DESCRIPTION:

The boiler tested at site H was a Combustion Engineering VU-40 pulverized coal-fired boiler with a rated steam flowrate of 32.0 kg/s of saturated steam at 4.2 MPa and 393°C. This tangentially fired boiler was equipped with three levels of pulverized coal burners in each furnace corner. The three levels are separated by two levels of steam-atomized oil burners. Generally, organic wastes are injected into the furnace with one of these oil burners. The unit is equipped with a cold side electrostatic precipitator for fly ash control. A methyl acetate waste stream spiked with CCl4, C6H5Cl, and 1,1,1-C2H3Cl3 was investigated in this test program

BULK FURNACE RESIDENCE TIME (CALCULATED):

2.0 s

BULK FURNACE TEMPERATURE (CALCULATED):

1370°C

OXYGEN (DRY BASIS):

5.1-6.2% (spread of 4 test measurements)

WASTE FEED COMPOSITION (POHCs ONLY):

Carbon tetrachloride, 1,1,1-trichloroethane, and chlorobenzene

CALCULATED POHC FEED RATES (G/S):

Specific data not reported.

CORRECTED AVERAGE VOLATILE PIC EMISSION RATES (UG/S):

Specific data not reported.

Volatile PICs observed were (relative percentages in parenthesis):
CH3Cl (92%), CHCl3 (2.7%), and C2Cl4 (2.6%).

CORRECTED SEMIVOLATILE PIC EMISSION RATES (UG/S):

Data not reported.

EMISSIONS ANALYSES:

	POHC Emissions	PIC Emissions	PIC:POHC Ratio
Range:	290-4100	4000-12000	
Average:	1600	6900	4.3125

SITE H - ACUREX

CONTAMINATION:
None evident.

TARGET COMPOUNDS FOR PIC ANALYSIS:
See Site D.

COMMENTS:
Data unavailable for detailed analysis of PIC emissions. Major volatile PIC was chloromethane. Apparently no semivolatile PIC analyses were conducted. PIC:POHC ratios were greater than unity, consistent with other emissions data for boilers.

APPENDIX B, cont

COMPARISON OF PIC AND POHC CONCENTRATIONS AT SITE L

DATE	TIME	SAMPLE PROTOCOL	FUEL	CONDITIONS	CCl_4 ng/l	C_6H_5Cl ng/l	TOTAL POHCs ng/l	Cl- PICs ng/l	ClPIC/POHC RATIO
25-Apr	1445	FULL VOST	GAS	TSB BASELINE	ND	ND	-	16.0	-
25-Apr	1606	FULL VOST	GAS	TSB BASELINE	ND	ND	-	7.0	-
25-Apr	1732	FULL VOST	GAS	TSB BASELINE	1.8	ND	1.8	16.0	8.8889
27-Apr	1446	FULL VOST	GAS	BASELINE	7.7	0.5	8.2	14.0	1.7073
27-Apr	1626	FULL VOST	GAS	BASELINE	6.5	0.4	6.9	11.0	1.5942
27-Apr	1755	FULL VOST	GAS	BASELINE	ND	0.6	0.6	8.0	13.3333
8-May	1154	MINI VOST	GAS	TSB HIGH GPM BASE	0.3	0.4	0.7	1.0	1.4286
8-May	1430	MINI VOST	GAS	TSB HIGH GPM BASE	1.3	11.0	12.3	2.0	0.1626
8-May	1447	MINI VOST	GAS	LOW GPM	280.0	ND	280.0	204.0	0.7286
8-May	1600	MINI VOST	GAS	NO ATOM.	4.8	62.0	66.8	6.0	0.0898
8-May	1642	MINI VOST	GAS	LOW GPM/O2	1.1	2.0	3.1	2.0	0.6452
8-May	1710	MINI VOST	GAS	LOW O2/WASTE INCREASE	ND	0.6	0.6	37.0	61.6667
8-May	1740	MINI VOST	GAS	LOW O2 BASELINE	0.8	ND	0.8	2.0	2.5000
8-May	2108	FULL VOST	GAS	WASTE OIL STARTUP	0.6	9.4	10.0	25.0	2.5000
8-May	2224	FULL VOST	GAS	LOW ATOM. STEAM (VARY)	1.43	28.7	30.1	36.0	1.1964
8-May	2332	MINI VOST	GAS	SOOT BLOW	4.8	73.0	77.8	7.0	0.0900
9-May	0020	MINI VOST	GAS	EA TRANSIENTS	ND	20.0	20.0	0.3	0.0150
9-May	0921	MINI VOST	GAS	START UP DUAL VOST	0.3	3.9	4.2	0.3	0.0714
9-May	1038	MINI VOST	GAS	LOW O2	2.0	12.0	14.0	10.0	0.7143
9-May	1142	MINI VOST	GAS	LOW O2/GPM	0.3	ND	0.3	52.0	173.3333
9-May	1311	MINI VOST	GAS	LOW O2/GPM	62.	31.0	93.0	2.0	0.0215
9-May	1410	MINI VOST	GAS	GAS BASELINE	18.	20.0	38.0	7.0	0.1842
9-May	1508	MINI VOST	GAS	LOAD REDUCTION	27.	12.0	39.0	101.0	2.5897
9-May	1702	FULL VOST	GAS	LOW LOAD/MODERATE O2	4.1	7.0	11.1	22.0	1.9820
9-May	1801	MINI VOST	GAS	LOW LOAD/LOW O2	28.0	19.0	47.0	8.0	0.1702
9-May	1946	MINI VOST	GAS	LOW LOAD/O2/GPM	9.0	10.0	19.0	3.0	0.1579
9-May	2018	MINI VOST	GAS	GPM TRANSIENTS	15.0	12.0	27.0	6.0	0.2222
9-May	2153	MINI VOST	GAS	LOAD INCREASE	2.0	0.7	2.7	1.0	0.3704
9-May	2301	MINI VOST	GAS	LOAD INCREASE	3.0	2.0	5.0	2.0	0.4000
9-May	2346	MINI VOST	GAS	SOOTBLOW/LOW LOAD	2.3	1.2	3.5	1.0	0.2857
10-May	0716	MINI VOST	OIL	LOW LOAD BASELINE	1.6	0.8	2.4	2.0	0.8333
10-May	0945	MINI VOST	OIL	LOW LOAD BASELINE	3.9	1.0	4.9	4.0	0.8163
10-May	1030	MINI VOST	OIL	WASTE STARTUP	124.0	98.0	222.0	8.0	0.0360
10-May	1132	MINI VOST	OIL	LOW LOAD/O2/GPM	42.0	41.0	83.0	8.0	0.0964
10-May	1408	MINI VOST	OIL	LOW LOAD BASELINE	24.0	3.0	27.0	4.0	0.1481
10-May	1452	MINI VOST	OIL	LOAD INCREASE	12.0	2.6	14.6	4.0	0.2740
10-May	1647	MINI VOST	OIL	BASELINE OIL/MODERATE LOAD	15.0	4.4	19.4	5.0	0.2577

COMPARISON OF PIC AND POHC CONCENTRATIONS AT SITE L

DATE	TIME	SAMPLE PROTOCOL	FUEL	CONDITIONS	CCl_4 ng/l	C_6H_5Cl ng/l	TOTAL POHCs ng/l	Cl- PICs ng/l	ClPIC/POHC RATIO
10-May	1750	MINI VOST	OIL	HIGH GMP/MODERATE LOAD	5.8	2.6	8.4	10.0	1.1905
10-May	1831	MINI VOST	OIL	MODERATE O2/HIGH GPM	0.3	0.9	1.2	1.0	0.8333
10-May	1917	MINI VOST	OIL	GPM TRANSIENTS	2.0	1.0	3.0	23.0	7.6667
10-May	2012	MINI VOST	OIL	START INVERTED SPRAY	14.0	3.3	17.3	37.0	2.1387
10-May	2055	MINI VOST	OIL	INVERTED SPRAY	7.6	1.0	8.6	29.0	3.3721
10-May	2134	MINI VOST	OIL	INVERTED SPRAY	4.9	0.5	5.4	87.0	16.1111
10-May	2222	MINI VOST	OIL	SOOTBLOW	8.8	2.7	11.5	144.0	12.5217
10-May	2313	MINI VOST	OIL	MIN. USUABLE ATOM.	2.5	33.0	35.5	164.0	4.6197
11-May	0007	MINI VOST	OIL	MIN. USUABLE ATOM.	4.5	1.7	6.2	145.0	23.3871
11-May	1430	MINI VOST	OIL	WASTE STARTUP	10.0	ND	10.0	3.0	0.3000
11-May	1528	MINI VOST	OIL	HIGH BASELINE	100.0	17.0	117.0	273.0	2.3333
11-May	2033	TRAP VOST	OIL	REDUCED ATOM.	0.7	2.1	2.8	88.0	31.4286
11-May	2118	TRAP VOST	OIL	SOOTBLOW	ND	1.4	1.4	56.0	40.0000
				ARITHEMETIC MEAN:	19.72	12.96	29.69	34.09	1.1483
								2.57E+49	
				GEOMETRIC MEAN:	4.95	4.17	9.53	9.73	1.0215

STATISTICAL ANALYSIS:

Effluent emissions ≥ 100 ng/l

PICs: Low waste feed (1), load reduction (1), soot blowing (1), poor atomization (2), high baseline (1)
POHCs: Low air (1), waste startup (1), high baseline (1), low waste feed (1)

Frequency of emissions ≥ 100 ng/l

POHCs: 4
PICs: 6

PIC/POHC Ratios:

PIC:POHC > 10.0 occurred 8 times out of 48 samples
Arithmetic mean PIC:POHC = 1.1
Geometric mean PIC:POHC = 1.0

PIC AND POHC EMISSIONS AT SITE M

TEST	CONDITIONS	POHC EMISSION RATE (ug/s)	Cl-PIC EMISSION RATE (ug/s)	ClPIC/POHC RATIO
MV-1	Baseline, low air, no oil	–	–	–
MV-2	Waste oil, lightoil, low air	–	691.4	NDe
MV-3	Baseline, normal load, normal air	–	–	–
MV-4	MCB spike, start	940.4	567.1	0.60
MV-5	Low air, smoky	2145.5	1863.9	0.87
MV-6	Low air, atomization off	1056.1	311.6	0.30
MV-7	Low load, no waste gas	3142.0	9631.4	3.07
MV-8	Smoky, low load, low air, no waste gas	–	0.0	NDe
MV-9	Maximum fan capacity	13.0	1443.7	111.05
MV-10	Maximum fan capacity	–	480.9	NDe
MV-11	Low air, hazy	30.3	1315.9	43.43
MV-12	Low air, hazy	8.8	1537.4	174.70
MV-13	High air	7.2	673.2	93.50
MV-14	Sootblowing	7.3	1568.4	214.85
MV-15	Sootblowing	2.2	2942.3	1337.41
MV-16	Residual POHC and PIC check, no oil	–	234.0	NDe
MV-17	Oil lightoff, low load	189.4	233.2	1.23
MV-18	Low load	188.7	305.5	1.62
MV-19	Low load, low air	121.2	122.5	1.01
MV-20	High oil firing	101.9	279.4	2.74
MV-21	High oil firing, smoky, low air	191.6	285.3	1.49
MV-22	High oil firing, smoky, low air	314.5	856.6	2.72
MV-23	Smoky, 2 top burners only	119.1	227.9	1.91
MV-24	Residual POHC and PIC check, no oil	–	126.3	NDe
MV-25	Residual POHC and PIC check, no oil	–	66.4	NDe
MV-26	Low load, lightoff, smoky	229.4	385.6	1.68
MV-27	Baseline with MCB, CCl4, TCB	70.5	434.3	6.16
MV-28	High air	60.8	224.0	3.68
MV-29	Sootblowing	–	296.2	NDe
MV-30	Sootblowing	449.3	260.6	0.58
MV-31	Oil lightoff, residual POHC and PIC check	–	672.8	NDe
MV-32	Normal load and normal air	308.3	268.3	0.87
MV-33	Normal load and normal air	440.8	367.8	0.83
MV-34	High CCl4	436.3	539.0	1.24
MV-35	High CCl4	457.2	209.6	0.46
MV-36	Low CCl4	544.0	184.8	0.34
MV-37	Low CCl4	205.6	172.9	0.84
MV-38	High CCl4	120.6	232.4	1.93

APPENDIX B. cont

PIC AND POHC EMISSIONS AT SITE M

TEST	CONDITIONS	POHC EMISSION RATE (ug/s)	CI-PIC EMISSION RATE (ug/s)	CIPIC/POHC RATIO
MV-39	Residual POHC and PIC check	–	168.5	NDe
MV-40	Residual POHC and PIC check	–	632.6	NDe
MV-41	Residual POHC and PIC check, no oil	–	642.4	NDe
MV-42	Unsteady oil flow, low load	252.0	2394.8	9.50
MV-43	High TCB	339.6	642.1	1.89
MV-44	High TCB	–	343.2	NDe
MV-45	High TCB, low air, smoky	765.6	515.9	0.67
MV-46	Reduced TCB, low air, hazy	79.6	578.5	7.27
MV-47	Reduced TCB, low air, hazy	79.6	716.5	9.00
MV-48	Sootblowing	266.7	676.7	2.54
MV-49	Residucal POHC and PIC check, no oil	–	3.9	NDe
MV-50	High air, no spikes	–	1518.7	NDe
MV-51	High air, high MCB and CCl4	290.4	104.2	0.36
MV-52	Low air, hazy stack	180.0	975.5	5.42
MV-53	Low air, smoky, high MCB and CCl4	163.5	157.4	0.96
MV-54	High MCB and CCl4	90.6	52.9	0.58
MV-55	High MCB and CCl4	103.6	26.5	0.26
FV-1	MCB spike start	39.7	89.4	2.25
FV-2	Low air, atomization off	–	426.0	NDe
FV-3	Low air, hazy	55.7	126.3	2.27
FV-4	Low load, low air	153.8	163.1	1.06
FV-5	Low load, lightoff, smoky	31.1	180.4	5.80
FV-6A	High air	120.8	438.5	3.63
FV-6B	High CCl4	564.7	750.9	1.33
FV-7	High CCl4	859.8	1283.7	1.49
FV-8	Residual POHC and PIC check	–	713.8	NDe
FV-9	Unsteady oil flow, low load	252.0	47.2	0.19
FV-10	High TCB, low air, smoky	765.6	3058.5	3.99
FV-11	High air, high MCB and CCl4	244.2	596.3	2.44
FV-12	Low air, hazy	189.5	226.9	1.20
FV-13	Low air, high smoke, high MCB and CCl4	172.3	594.0	3.45
	Arithmetic Mean:	352.20	729.22	2.07
		1.16E+112	2.04E+131	6.94E+38
	Geometric Mean:	157.21	378.26	2.41

PIC AND POHC EMISSIONS AT SITE M

STATISTICAL ANALYSIS:

Effluent emissions ≥ 1000 ug/s

PICs: High air (1), low air (5), soot blowing (2), unstable waste feed (1), high Cl (2)
POHCs: Low air (2)

Frequency of emissions ≥ 1000 ug/s

POHCs: 3
PICs: 12

PIC/POHC Ratios:

PIC:POHC > 10.0 occurred 7 times out of 68 samples
Arithmetic mean PIC:POHC = 2.4
Geometric mean PIC:POHC = 2.1

POHC AND PIC EMISSIONS AT SITE N

Test Condition	POHC Type	POHC Feedrate (g/sec)	POHC Emission Conc. (ug/dscm)	POHC Emission rate (g/s)	DRE (%)	CLPIC Emission Conc. (ug/dscm)	NonCLPIC Emission Conc. (ug/dscm)	CLPIC:POHC Ratio
1	–	–	–	–	–	93.0	4800	–
2	–	–	–	–	–	25.0	NA	–
3	–	–	–	–	–	28.0	NA	–
4	–	–	–	–	–	20.0	NA	–
5	–	–	–	–	–	97.0	780.0	–
6	TCE	17.62	1.8	2.90E-05	99.9998	61.0	1180.0	33.9
7	TCB	19.72	0.9	1.70E-05	99.9999	15.0	NA	16.7
8	TCE	18.55	4.9	7.80E-05	99.9996	90.0	460.0	18.4
9	TCE	40.80	0.8	1.20E-05	100.0000	40.0	NA	50.0
10	TCE	21.33	ND	ND	100.0000	6.7	NA	NDe
11	TCE	20.40	0.6	7.00E-06	100.0000	41.0	4.7	68.3
12	TCB	22.68	9.6	1.20E-04	99.9995	100.0	NA	10.4
13	TCB	20.71	3.4	5.90E-05	99.9997	15.0	NA	4.4
14	TCE	19.47	0.2	2.50E-06	100.0000	38.0	NA	190.0
14A	–	–	–	–	–	127.0	NA	–
15	TCB	19.72	2.0	3.20E-05	99.9998	57.0	NA	28.5
16	TCB	20.71	4.7	7.40E-05	99.9996	15.0	NA	3.2
17	–	–	–	–		450.0	2900.0	–
	Arithmetic Mean:		2.89	4.31E-05	99.9998	73.26	1687.45	25.3
	Geometric Mean:		1.73	2.62E-05	99.9998	43.69	550.76	25.3

NA: Not available. Sampling and analysis not performed or loss of data due to analytical problems.
ND: Not detected.
NDe: Not defined.

STATISTICAL ANALYSIS:

Frequency of emissions ≥ 100 ug/dscm
POHCs: 4
PICs: 4

PIC/POHC Ratios:
PIC:POHC > 10.0 occurred 8 times out of 10 samples
Arithmetic mean PIC:POHC = 25.3
Geometric mean PIC:POHC = 25.3

APPENDIX C

GENERAL PORTLAND - PAULDING, OH

SITE DESCRIPTION:

General Portland's Paulding plant is a representative wet process cement kiln. The plant is equipped with an electrostatic precipitator for emission control. Tests included 4 days of baseline testing, 3 days of testing with waste fuel containing less than 1% chloride (test 5-7), and 2 days of testing with waste fuel spiked with Freon 113 and containing ca. 4% chloride (tests 8-9).

BULK FURNACE RESIDENCE TIME (CALCULATED):

Not reported.

BULK FURNACE TEMPERATURE (CALCULATED):

Not reported.

CARBON DIOXIDE (DRY BASIS?)

12.9-13.1% (spread of baseline and waste burn measurements).

OXYGEN (DRY BASIS?):

12.0-12.3% (spread of baseline and waste burn measurements)

WASTE FEED COMPOSITION (POHCs ONLY):

Methylene chloride, methyl ethyl ketone, 1,1,1-trichloroethane, toluene, and 1,1,2-trichloro-1,2,2-trifluoroethane (Freon 113).

CORRECTED AVERAGE POHC EMISSION RATES (UG/S):

	DCM	MEK	1,1,1-TCA	Toluene	Freon 113	Total
Baseline	610	769	44.3	4703	< 21.8	6126.30
≤ 1% Cl	716	586	153	4998	< 23.7	6453.00
≤ 4% Cl	1785	479	145	4250	< 25.4	6659.00

Footnote:

1. DCM: dichloromethane, MEK: methyl ethyl ketone, 1,1,1-TCA: 1,1,1-trichloroethane,

CORRECTED AVERAGE VOLATILE PIC EMISSION RATES (UG/S):

	Benzene	Chloroform	PCE [1]	1,1,2-TCA [2]
Baseline	36300	100	820	110
≤ 1% Cl	34300	457	2550	150
≤ 4% Cl	342850	2200	BDL	BDL

Footnote:

1. PCE = Tetrachloroethylene; 1,1,2-TCA: 1,1,2-Trichloroethane.

GENERAL PORTLAND - PAULDING, OH

CORRECTED SEMIVOLATILE ORGANIC EMISSION RATES (UG/S):

	Styrene	Ethylbenzene	Xylene	Biphenyl	Naphthalene	Methylnaphthalene
Baseline	4.9	0.82	2.92	2.5	12.3	8.33
≤ 1% Cl	6.8	1.1	2.7	1.2	13.5	6.3
≤ 4% Cl	5.4	0.76	1.4	0.83	10.7	2.7

	C3-benzenes	C4-benzenes	C5-benzenes	C6-benzenes
Baseline	5.8	5.2	0.67	0.26
≤ 1% Cl	3.1	5.3	0.65	0.88
≤ 4% Cl	21.0	2.7	0.47	0.135

EMISSIONS ANALYSES:

	Total Emissions	POHC Emissions	PIC Emissions (less phthalates)	CLPIC Emissions	PIC:POHC Ratio
Baseline	43500.0	6126.3	37342.30	1030	6.10
≤ 1% Cl	43951.5	6453	37470.50	3157	5.81
≤ 4% Cl	351755.1	6659	345060.70	2200	51.82

CONTAMINATION:

Phthalates were observed in the sampling, they were not included as PICs in calculation of PIC:POHC ratios.

TARGET COMPOUNDS FOR PIC ANALYSIS:

Not specified.

COMMENTS:

POHC feed rates were unavailable to determine the % PIC emissions (per unit POHC input). Chloroform, tetrachloroethylene, and benzene were the major PICs observed. PIC:POHC ratios were all much larger than unity, with the 4% Cl test yielding a value of 52.0. Semivolatile emissions were much less than volatile emissions. Sampling of particulates for organic matter was not conducted. Sampling for PCBs, PCPs, PCDDs and PCDFs was conducted. The results were negative with a detection limit of 1 ng/1ul.

SAN JUAN CEMENT COMPANY

SITE DESCRIPTION:

The San Juan Cement Company is dedicated to the manufacture of portland cement. The wet process countercurrent cement kiln is a large steel horizontal tube with refractory linings. The feed material was a slurry of ca. 35-39% water and finely crushed rock. The primary fuel was a No. 6 fuel oil, burned at ca. 1.51E-3 m3/s; the resulting heat input was 62 MW (212 MBtu/hr). The particulate control device was a fabric filter baghouse.

ESTIMATED GAS RESIDENCE TIME:

Not reported.

PROCESS TEMPERATURE:

ca. 1370-1450°C

CARBON DIOXIDE (DRY BASIS)

Not reported.

OXYGEN (DRY BASIS):

Not reported.

WASTE FEED COMPOSITION (POHCs ONLY):

Methylene chloride, chloroform, and carbon tetrachloride.

CORRECTED AVERAGE POHC EMISSION RATES (G/HR):

	DCM [1]	Chloroform	Carbon tetrachloride	Total
Baseline average	46	374	2361	2781
W1-2	< 7.9	< 22.2	78	78
W2-1	12.2	< 19	<.5	12.2
W3-1	< 6.6	26.2	917.1	943.3
W3-2	53.1	28	580.1	661.2
W3-3	535.7	< 19.9	225.4	761.1
W4-1	1124.9	448.1	1433.7	3006.7
W4-2	369.2	167.8	1180.2	1717.2
W4-3	678.1	449.9	1070	2198
W4-4	9.7	317	194.1	520.8
W4-5	771.5	28.9	1069.5	1869.9
W6-1	279.4	-	-	279.4

APPENDIX C, cont.

SAN JUAN CEMENT COMPANY

CORRECTED AVERAGE POHC EMISSION RATES (G/HR):

W5-1	556.5	495.3		298.4	1350.2
W5-2	346.1	1451		418.2	2215.3
W4/6-1	134.7	475.8		1185.2	1795.7
W4/6-2	285.3	1303.1		209.1	1797.5
W4/6-3	89.8	51.7		406.9	548.4
W4/6-4	323.4	< 19		1040.9	1364.3
W4/6-5	482.6	440.9		1362.1	2285.6

Footnote:

1. DCM: dichloromethane.

CORRECTED SEMIVOLATILE ORGANIC EMISSION RATES (MG/HR):

	C2-Alkyl benzene	Benzaldehyde	Phenol	1-Phenylethanone	Naphthalene	Benzoic acid
Baseline average	ND	ND	ND	ND	ND	ND
W3-1	ND	9.84	10.99	ND	3.12	3.47
W4-4	ND	ND	ND	ND	12.75	38.55
W6-1	1.98	17.79	2.44	6.13	22.67	47.45
	C2-Naphthalene	Benzene	C3-Naphthalene	1,2-Benzenediol	1,1'-Diethylbiphenyl	
Baseline average	ND	ND	ND	ND	ND	
W3-1	185.24	ND	188.59	ND	ND	
W4-4	ND	41.51	ND	25.21	111.2	
W6-1	ND	ND	ND	ND	ND	
		1,1-bis(p-ethylphenyl) ethane		Sulfur (S8)	1,1'-Biphenyl	
Baseline average		ND		68.82	ND	
W3-1		ND		830.78	38.76	
W4-4		8.6		2825.39	6.38	
W6-1		ND		340.07	7.25	

EMISSIONS ANALYSES:

	POHC Emissions	PIC Emissions (less volatiles)	PIC:POHC Ratio
Baseline average	2781	0.00	0.000000
W3-1	661.2	14.11	0.000021
W4-4	520.8	54.26	0.000104
W6-1	279.4	25.11	0.000090

CONTAMINATION:

The degree of product analysis was insufficient to discern if any contamination existed.

SAN JUAN CEMENT COMPANY

TARGET COMPOUNDS:

Not specified.

COMMENTS:

Emissions data likely unreliable due to the lack of measurement of volatile emissions. It should also be noted that the kiln did not employ scrubbers for HCl removal. Particulate sampling of the stack was not conducted. Sampling for PCDDs in stack gases and particulates were negative. Sampling for PCDFs in particulates were also negative. Trace quantities of PCDD, HexaCDD, and HeptaCDD congeners were detected in the stack gases of run W3-1.

SITE I (ACUREX STUDY)

SITE DESCRIPTION:

Site I is a rotary kiln dryer tested at a capacity of about 10 kg/s when fired with a heat input capacity of ca.11 MW (37.5 MBtu/hr). The fuel fired in this test was waste oils and waste solvents. The feed material was earth-type clays whose moisture content typically reduced from 50% to 8%. The particulate control device was a fabric filter baghouse.

ESTIMATED GAS RESIDENCE TIME:

2.5 s

PROCESS TEMPERATURE:

590-650°C

CARBON DIOXIDE (DRY BASIS)

3.6-4.0% (spread of 3 runs).

OXYGEN (DRY BASIS):

14.9-16.4% (spread of 3 runs)

WASTE FEED COMPOSITION (POHCs ONLY):

1,1,1-trichloroethane, trichloroethylene, benzene, tetrachloroethylene, toluene, chlorobenzene, methyl ethyl ketone, 1,1,2-trifluoro-1,2,2-trichloroethane (Freon 113).

CORRECTED AVERAGE POHC EMISSION RATES (UG/S):

	1,1,1-TCA [1]	TCE [1]	Benzene	PCE [1]	Toluene	hlorobenzene
Test 1	57	14	1380	41	580	18.00
Test 2	38	ND	190	5.6	210	17.00
Test 3	9.4	ND	122	ND	200	18.00

	MEK [1]	Freon 113	Total
Test 1	61	143	2294
Test 2	35	26	521.6
Test 3	14	16	379.4

Footnote:

1. 1,1,1-TCA: 1,1,1-trichloroethane, TCE: trichloroethylene, PCE: tetrachloroethylene, MEK: methyl ethyl ketone.

SITE I (ACUREX STUDY)

CORRECTED AVERAGE VOLATILE PIC EMISSION RATES (UG/S):

	Chloromethane	Bromomethane	Chloroethene	DCM [1]	1,1-DCE [1]	Chloroform
Test 1	4.5	7.7	44	72	55	3.9
Test 2	67	11	21	17	ND	3.6
Test 3	24	5.2	18	ND	ND	ND

	Carbon tetrachloride	Chloroethane	Total
Test 1	494	ND	681.1
Test 2	20	4.1	143.7
Test 3	4.1	ND	51.3

Footnote:

1. DCM = dichloromethane, 1,1-DCE: 1,1-dichloroethane.

CORRECTED SEMIVOLATILE PIC EMISSION RATES (UG/S):

	Phenol	Naphthalene	DMPh [1]	2,6-DNT [1]	DBPh [1]	2-CP	bis(2-chlorohexyl)phthalate
Test average	52	9.6	36	7.7	43	12	34

Footnote:

1. 2-CP: 2-Chlorophenol, DMPh: Dimethyl phthalate, 2,6-DNT: 2,6-dinitrotoluene, DBPh: dibutyl phthalate

EMISSIONS ANALYSES:

	POHC Emissions	PIC Emissions (less phthalates and semivolatiles)	% PIC Emissions (per waste input)
Test 1	2294.0	681.1	3.64E-04
Test 2	521.6	143.7	6.78E-05
Test 3	379.4	51.3	2.43E-05

	Waste Feedrate	POHC Feedrate	CLPOHC Feedrate	CLPIC Emissions	% PIC Emissions (per POHC input)	PIC:POHC Ratio	% CIPIC Emissions (per CIPOHC input)
Test 1	186.9	1.8192	1.5307	673.4	0.0374	0.30	0.0445
Test 2	211.82	1.8192	1.5307	132.7	0.0079	0.28	0.0094
Test 3	210.93	1.8192	1.5307	46.1	0.0028	0.14	0.0034

	Total Emissions	% Emissions (per fuel/waste input)	% CCL4 Emissions (per CLPOHC input)	% C2H3CL Emissions (per CLPOHC input)
Test 1	3650.4	0.0020	0.0323	0.0029
Test 2	9903	0.0047	0.0013	0.0014
Test 3	13838	0.0066	0.0003	0.0012

CONTAMINATION:

Phthalates were observed in the sampling. Semivolatile PICs (including phthalates) were not included in calculated PIC:POHC ratios because test specific data were not available.

APPENDIX C, cont

SITE I (ACUREX STUDY)

TARGET COMPOUNDS FOR PIC ANALYSIS:
Volatiles:

Chloromethane
Dichloroform
Chloroform
Tetrachloromethane
Chloroethane
1,1-Dichloroethane
1,2-Dichloroethane
1,1,1-Trichloroethane
1,1,2-Trichloroethane
1,1,2,2-Tetrachloroethane
1,2-Dichloropropane
Hexachlorocyclohexane
Vinyl chloride
1,1-Dichloroethylene
1,2-Dichloroethylene
Trichloroethylene
Tetrachloroethylene
Allyl chloride
1,3-Dichloropropene
Chloroprene

Ethylene oxide
Propylene oxide

Epichlorohydrin
2-Chloroethyl vinyl ether

Acetaldehyde
Acrolein

Acrylonitrile

Benzene
Toluene
Ethyl benzene
o-Xylene
m-Xylene
p-Xylene

Chlorobenzene

TARGET COMPOUNDS FOR PIC ANALYSIS:
Semivolatiles:

Acid Compounds

2,4,6-Trichlorophenol
p-Chloro-m-cresol
2-Chlorophenol
2,4-Dichlorophenol
2,4-dimethylphenol

2-Nitrophenol
4-Nitrophenol
2,4-Dinitrophenol
4,6-Dinitrophenol
Pentachlorophenol
Phenol

SITE I (ACUREX STUDY)

TARGET COMPOUNDS FOR PIC ANALYSIS:
Semivolatiles:

Base Neutral Compounds

- 1,2,4-Trichlorobenzene
- 1,2-Dichlorobenzene
- 1,2-Diphenylhydrazine (as azobenzene)
- 1,3-Dichlorobenzene
- 1,4-Dichlorobenzene
- 2,4-Dinitrotoluene
- 2,6-Dinitrotoluene
- 2-Chloronaphthalene
- 3,3'-Dichlorobenzidine
- 3-Methyl cholanthrene
- 4-Bromophenyl phenyl ether
- 4-Chlorophenyl phenyl ether
- 7,12-Dimethyl benz(a)anthracene
- N-Nitrosodi-n-propylamine
- N-Nitrosodimethylamine
- N-Nitrosodiphenylamine
- Acenaphthene
- Acenaphthylene
- Anthracene
- Benzo(ghi)perylene
- Benzidine
- Benzo(b)fluoranthene
- Benzo(k)fluoranthene
- Benzo(a)anthracene
- Benzo(a)pyrene
- Benzo(c)phenanthrene
- bis(2-Chloroethoxy)methane
- bis(2-Chloroethyl)ether
- bis(2-Chloroisopropyl)ether
- bis(2-Ethylhexyl)phthalate
- Butyl benzyl phthalate
- Chrysene
- Di-n-butyl phthalate
- Di-n-octyl phthalate
- Dibenzo(a,h)anthracene
- Dibenzo(c,g)carbazole
- Diethyl phthalate
- Dimethyl phthalate
- Fluoroanthene
- Fluorene
- Hexachlorobenzene
- Hexachlorobutadiene
- Hexachlorocyclopentadiene
- Hexachloroethane
- Indeno(1,2,3-cd)pyrene
- Isophorone
- Naphthalene
- Nitrobenzene
- Perylene
- Phenanthrene
- Pyrene

COMMENTS:

Chloroform, dichloromethane, carbon tetrachloride, vinyl chloride, and phenol were the major PICs observed. PIC:POHC ratios in this study were consistently less than unity. With the exception of test 3 semivolatile emissions were less than volatile emissions. Sampling of particulates for organic matter and for PCBs, PCPs, PCDDs and PCDFs was not conducted.

SITE II (ACUREX STUDY)

SITE DESCRIPTION:

Site II is a rotary aggregate kiln processing shales into lightweight aggregate material. The kiln capacity is ca. 2.5 kg/s with a typical operating values of 2.3-2.5 kg/s. The required heat input is 7.9-8.8 MW (26-30 MBtu/hr). The fuel burned is generally a combination of pulverized coal and hazardous waste solvents injected through two concentric burners. Particulates are removed from the stack gases with two separate devices: a multiclone and a crossflow gravity spray wet scrubber.

ESTIMATED GAS RESIDENCE TIME:

2.3 sec.

PROCESS TEMPERATURE:

1120-1180°C

CARBON DIOXIDE (DRY BASIS)

6.0-13.1% (spread of 4 runs; cofiring of coal and waste fuel).
6.7-11.9% (spread of 4 runs; waste fuel firing).

OXYGEN (DRY BASIS):

5.0-11.0% (spread of 4 runs; cofiring of coal and waste fuel).
5.0-10.0% (spread of 4 runs; waste fuel firing).

WASTE FEED COMPOSITION (POHCs ONLY):

Methylene chloride, 1,2-dichloroethane, 1,1,1-trichloroethane, carbon tetrachloride, trichloroethylene, benzene, tetrachloroethylene, toluene, chlorobenzene, methyl ethyl ketone, 1,1,2-trifluoro-1,2,2-trichloroethane (Freon 113).

CORRECTED AVERAGE POHC EMISSION RATES (UG/S):

	DCM [1]	1,2-DCE [1]	1,1,1-TCE [1]	Carbon tetrachloride	TCE [1]	Benzene	PCE [1]
Test 1	ND	1.2	ND	15.3	3.5	42	7.1
Test 2	ND		ND	1.9	0.93	26	2.1
Test 3	ND		ND	1.7	1.6	36.1	1.8
Test 4	ND		1.8	2.5	1.8	35.1	1.7

	Toluene	Chlorobenzene	MEK [1]	Freon 113	Total
Test 1	21.3	17.5		0.9	108.8
Test 2	18.3	15.3		0.8	65.33
Test 3	95.3	22.6	50.1	0.5	209.7
Test 4	100	20	58	1.5	222.4

Footnote:

1. DCM: dichloromethane, 1,1-DCE: 1,1-dichloroethane, 1,1,1-TCA: 1,1,1-trichloroethane, TCE: trichloroethylene, PCE: tetrachloroethylene, MEK: methyl ethyl ketone.

SITE II (ACUREX STUDY)

BLANK CORRECTED AVERAGE VOLATILE PIC EMISSION RATES (UG/S):

	Chloromethane	Bromomethane	Chloroethene	1,1-DCE [1]	t-1,2-DCE [1]	Chloroform
Test 1	156	7.2	12	4	1.4	8.6
Test 2	547	37	18.7	1.9	0.5	2.3
Test 3	600	8.9	14	2	1	5.1
Test 4	968	8.1	13	2.8	1.1	6.4
		Carbon tetrachloride		Total		
Test 1		15.3		204.5		
Test 2		1.9		609.3		
Test 3		1.7		632.7		
Test 4		2.5		1001.9		

Footnote:

1. 1,1-DCE: 1,1-dichloroethylene, t-1,1-DCE: trans-1,2-dichloroethylene.

EMISSIONS ANALYSES:

	POHC Emissions	PIC Emissions	Total Emissions	% Emissions (per fuel/waste input)	% PIC Emissions (per waste input)	PIC:POHC Ratio	% PIC Emissions (per POHC input)	% PIC Emissions (per fuel/waste input)
Test 1	108.8	204.50	313.7	0.000090	9.39E-05	1.88	0.0012	0.000059
Test 2	65.33	609.30	705.53	0.000203	3.44E-04	9.33	0.0035	0.000175
Test 3	209.7	632.70	901.87	0.000325	2.28E-04	3.02	0.0036	0.000228
Test 4	222.4	1001.90	1312.4	0.000464	3.54E-04	4.50	0.0057	0.000354
	Waste Feed Rate	CLPIC Emissions	POHC Feed Rate	CLPOHC Feedrate	% CIPIC Emissions (per CIPOHC input)	Fuel Feedrate	% CH3CL Emissions (per CIPOHC input)	% C2H3CL Emissions (per CIPOHC input)
Test 1	217.8	197.3	17.44	4.68	0.0042	130.0299	0.0033	0.0003
Test 2	177.3	572.3	17.44	4.68	0.0122	170.4808	0.0117	0.0004
Test 3	277.2	623.8	17.44	4.68	0.0133		0.0128	0.0003
Test 4	283.02	993.8	17.44	4.68	0.0212		0.0207	0.0003

CONTAMINATION:

Bromomethane inconsistent with waste feed composition; this compound was likely produced from one of the following:

1. stripping of volatile compounds from scrubber water
2. PIC from brominated compounds in waste whose concentrations are less than 100 ug/g.

TARGET COMPOUNDS FOR PIC ANALYSIS:

See Site I

COMMENTS:

Chloromethane was the major volatile PIC observed; sampling for semivolatile PICs was not conducted. PIC:POHC ratios ranged from 1.9 to 9.3. With the exception of test 1, emissions from Site II were much greater than from site I. Sampling of particulates for organic matter and for PCBs, PCPs, PCDDs, and PCDFs was not conducted.

APPENDIX D

EPA-CRF SYSTEMS RELIABILITY EPA-IRF CHLORINATED BENZENE STUDY

SITE DESCRIPTION:

This initial study at the EPA-CRF consisted of process characterization and the reporting of results of 34 detailed engineering and chemical studies of the incineration of synthetic hazardous wastes. Experimental results described within have been obtained with a rotary kiln/afterburner system with venturi and packed-tower scrubbers. The tests employed hexachlorobenzene and 1,2,4-trichlorobenzene as surrogate principal organic hazardous constituents.

EXPERIMENTAL RESULTS (OPERATIONAL PARAMETERS):

Rotary Kiln

Sample ID	Kiln T, °C	O2 (%)	CO2 (%)	CO (ppm)	POHC	POHC Feed (ug/min)	C3H8 Feed (ug/min)	Waste Feed (ug/min)	Total Feed (ug/min)	Waste:Fuel Feed Ratio
S08021050	871	N/A	N/A	N/A	HexCBz	1.67E+06	0.00E+00	4.01E+07	4.17E+07	No Fuel
S08021250	871	N/A	N/A	N/A	HexCBz	1.67E+06	0.00E+00	4.01E+07	4.17E+07	No Fuel
S08101045	871	N/A	N/A	N/A	HexCBz	1.67E+06	0.00E+00	4.01E+07	4.17E+07	No Fuel
S08101300	871	N/A	N/A	N/A	HexCBz	1.67E+06	0.00E+00	4.01E+07	4.17E+07	No Fuel
S08121000	760	10.9	N/A	N/A	HexCBz	1.67E+06	0.00E+00	4.01E+07	4.17E+07	No Fuel
S08121130	760	10.9	N/A	N/A	HexCBz	1.67E+06	0.00E+00	4.01E+07	4.17E+07	No Fuel
S08190950	700	6.1	N/A	N/A	HexCBz	1.67E+06	1.95E+08	4.01E+07	2.37E+08	0.2
S08191130	715	7.6	N/A	N/A	HexCBz	1.67E+06	2.01E+08	4.01E+07	2.42E+08	0.2
S08230945	643	N/A	N/A	N/A	None	0.00E+00	1.95E+08	0.00E+00	1.95E+08	0.0
S08231107	685	N/A	N/A	N/A	None	0.00E+00	2.01E+08	0.00E+00	2.01E+08	0.0
S08251110	871	N/A	N/A	N/A	None	0.00E+00	5.66E+08	0.00E+00	5.66E+08	0.0
S08251250	871	N/A	N/A	N/A	None	0.00E+00	4.73E+08	0.00E+00	4.73E+08	0.0
S09011035	871	N/A	N/A	N/A	TriCBz	1.67E+06	3.60E+08	4.00E+07	4.01E+08	0.1
S09011212	871	N/A	N/A	N/A	TriCBz	1.67E+06	2.67E+08	4.00E+07	3.09E+08	0.1
S09061046	871	N/A	N/A	N/A	TriCBz	8.33E+06	4.35E+08	3.60E+07	4.79E+08	0.1
S09061225	871	N/A	N/A	N/A	TriCBz	8.33E+06	3.87E+08	3.60E+07	4.32E+08	0.1
S09081116	871	N/A	N/A	N/A	TriCBz	1.67E+07	3.58E+08	3.11E+07	4.06E+08	0.1
S09081258	871	N/A	N/A	N/A	TriCBz	1.67E+07	3.65E+08	3.11E+07	4.13E+08	0.1
S09131057	871	N/A	N/A	N/A	None	0.00E+00	5.60E+08	0.00E+00	5.60E+08	0.0
S09131224	871	N/A	N/A	N/A	None	0.00E+00	5.10E+08	0.00E+00	5.10E+08	0.0
S09221138A	871	N/A	N/A	N/A	None	0.00E+00	5.50E+08	0.00E+00	5.50E+08	0.0
S09221138B	871	N/A	N/A	N/A	None	0.00E+00	5.10E+08	0.00E+00	5.10E+08	0.0
K10201120	871	N/A	N/A	N/A	None	0.00E+00	NA	0.00E+00	NA	NA
K10261107	871	N/A	N/A	N/A	None	0.00E+00	NA	0.00E+00	NA	NA
K10261248	871	N/A	N/A	N/A	None	0.00E+00	NA	0.00E+00	NA	NA
K10281100	871	N/A	N/A	N/A	None	0.00E+00	NA	0.00E+00	NA	NA
K10281248	871	N/A	N/A	N/A	None	0.00E+00	NA	0.00E+00	NA	NA
K11011139	760	N/A	N/A	N/A	None	0.00E+00	5.66E+08	0.00E+00	5.66E+08	0.0
K11011302	760	N/A	N/A	N/A	None	0.00E+00	4.97E+08	0.00E+00	4.97E+08	0.0

EPA-CRF SYSTEMS RELIABILITY EPA-IRF CHLORINATED BENZENE STUDY

EXPERIMENTAL RESULTS (OPERATIONAL PARAMETERS):

Rotary Kiln Sample ID	Kiln T, °C	O_2 (%)	CO_2 (%)	CO (ppm)	POHC	POHC Feed (ug/min)	C_3H_8 Feed (ug/min)	Waste Feed (ug/min)	Total Feed (ug/min)	Waste:Fuel Feed Ratio
K11031041	760	8.75	N/A	N/A	None	0.00E+00	NA	0.00E+00	NA	NA
K11031207	760	8.75	N/A	N/A	None	0.00E+00	NA	0.00E+00	NA	NA
K11091008	760	N/A	N/A	N/A	None	0.00E+00	NA	0.00E+00	NA	NA
K11091136	760	N/A	N/A	N/A	None	0.00E+00	NA	0.00E+00	NA	NA
K11111039	871	N/A	N/A	N/A	TriCBz	1.67E+06	4.80E+08	4.00E+07	5.22E+08	0.1
K11111210	871	N/A	N/A	N/A	TriCBz	1.67E+06	4.80E+08	4.00E+07	5.22E+08	0.1
K11181113	787-760	(a)	5.8	<1	TriCBz	6.67E+07	0.00E+00	6.67E+07	1.33E+08	No Fuel
K11181125	732-704	(a)	5.2	2.3	TriCBz	6.67E+07	0.00E+00	6.67E+07	1.33E+08	No Fuel
K11181136	677-649	(a)	5.6	6	TriCBz	6.67E+07	0.00E+00	6.67E+07	1.33E+08	No Fuel
K11221045	760	8.25	8.2	<1	TriCBz	1.67E+06	0.00E+00	4.00E+07	4.17E+07	No Fuel
K11221205	760	9.5	7.5	<1	TriCBz	1.67E+06	0.00E+00	4.00E+07	4.17E+07	No Fuel
K12061309A	760	N/A	N/A	N/A	TriCBz	1.67E+06	0.00E+00	4.00E+07	4.17E+07	No Fuel
K12061309B	760	N/A	N/A	N/A	TriCBz	1.67E+06	0.00E+00	4.00E+07	4.17E+07	No Fuel
K12061309C	760	N/A	N/A	N/A	TriCBz	1.67E+06	0.00E+00	4.00E+07	4.17E+07	No Fuel
K12131022	760	7.75	8.4	<1	None	0.00E+00	3.70E+08	0.00E+00	3.70E+08	0.0
K12131040	760	7.75	8.4	<1	None	0.00E+00	3.70E+08	0.00E+00	3.70E+08	0.0
K12131224	760	8.25	8	<1	None	0.00E+00	3.70E+08	0.00E+00	3.70E+08	0.0
K01131109	538	12.0	0.6	~20	TriCBz	1.67E+06	2.69E+08	4.00E+07	3.10E+08	0.1
K01131211	538	12.0	0.4	~10	TriCBz	1.67E+06	2.69E+08	4.00E+07	3.10E+08	0.1
K01131252	538	12.0	0.3	2 - 4	TriCBz	1.67E+06	2.69E+08	4.00E+07	3.10E+08	0.1
K01241050	538	N/A	6.4	3	None	0.00E+00	NA	0.00E+00	NA	NA
K01241225	538	N/A	7.7	2	None	0.00E+00	NA	0.00E+00	NA	NA
K01241350	538	N/A	7.8	>100	TriCBz	1.67E+06	0.00E+00	4.00E+07	4.17E+07	No Fuel
K01261120	510	10.7	6.3	>100	None	0.00E+00	2.46E+08	0.00E+00	2.46E+08	0.0
K01261323	510	11.5	6.3	>100	None	0.00E+00	2.46E+08	0.00E+00	2.46E+08	0.0
K01261444	510	11.7	6.1	>100	HexCBz	1.67E+06	2.46E+08	4.01E+07	2.88E+08	0.2

EPA-CRF SYSTEMS RELIABILITY EPA-IRF CHLORINATED BENZENE STUDY

EXPERIMENTAL RESULTS (OPERATIONAL PARAMETERS):

Afterburner:

Sample ID	AB Temp, °C	O2 (%)	CO2 (%)	CO (ppm)	tr (s)
S08021050	1093	12.0	6.5	<1	1.23
S08021250	1093	12.0	6.2	<1	1.23
S08101045	1093	7.5	8.0	<1	1.28
S08101300	1093	7.5	8.1	<1	1.28
S08121000	982	10.0	7.4	<1	1.53
S08121130	982	10.0	7.4	<1	1.53
S08190950	877	11.0	7.0	<1	1.91
S08191130	877	11.0	7.0	<1	1.91
S08230945	877	10.0	7.2	<1	1.95
S08231107	877	10.0	6.5	<1	1.79
S08251110	1093	7.0	8.4	<1	1.26
S08251250	1093	7.0	8.4	<1	1.28
S09011035	1071	7.5	8.6	<1	1.35
S09011212	1071	16.3	4.5	<1	1.55
S09061046	1066	7.0	8.6	<1	1.41
S09061225	1093	7.0	8.2	<1	1.31
S09081116	1093	7.5	8.4	<1	1.31
S09081258	1093	7.5	8.0	<1	1.42
S09131057	1093	8.2	(a)	<1	1.19
S09131224	1093	(a)	(a)	<1	1.19
S09221138A	1093	8.5	7.3	<1	1.05
S09221138B	1093	8.5	7.3	<1	1.05
A10201120	1093	8.0	7.6	<1	1.38
A10261107	1093	(a)	(a)	(a)	1.28
A10261248	1093	(a)	(a)	(a)	1.28
A10281100	1093	7.5	8.4	<1	1.34
A10281248	1093	8.25	8.0	<1	1.33
A11011139	982	(a)	(a)	(a)	1.47
A11011302	982	(a)	(a)	(a)	1.57
A11031041	871	11.25	6.4	<1	1.76
A11031207	871	10.5	7.1	~1	2.13
A11091008	871	10.5	6.6	<1	1.81
A11091136	871	11.0	6.2	<1	1.93
A11111039	1093	6.5	8.8	<1	1.45
A11111210	1093	6.5	8.0	<1	1.45
A11181113	1093	7.5	8.0	<1	1.27

APPENDIX D, cont

EPA-CRF SYSTEMS RELIABILITY EPA-IRF CHLORINATED BENZENE STUDY

EXPERIMENTAL RESULTS (OPERATIONAL PARAMETERS):

Afterburner:

Sample ID	AB Temp, °C	O2 (%)	CO2 (%)	CO (ppm)	tr (s)
A11221045	871	8.5	8.0	~2	1.65
A11221205	871	8.0	7.1	~2	1.65
A01131109	1027	8.5	9.5	~1.5	2.16
A01241050	899	10.0	7.6	<1	2.32
A01241225	899	10.5	7.5	<1	2.25
A01241350	899	10.7	7.4	<1	2.3
A01261120	815	11.5	5.2	<1	2.4
A01261323	815	10.75	5.5	<1	2.35
A01261444	815	11.0	6.1	<1	2.31

EXPERIMENTAL RESULTS (ORGANIC EMISSIONS, UG/MIN):

Sample ID	CI5-EANE	1,3-DCBz	1,4–DCBz	CL6-EANE	1,2-DCBz	BzCL	1,3,5-TCBz	HC-1,3-BD	1,2,4-TCBz
S08101045	<0.11	41.6	<3.5	10.6	7.5	32.8	<0.60	<0.14	2.82
S08101300	<0.11	43.8	13.5	18.3	<1.4	31.3	3.13	0.871	7.15
S08121000	<0.11	45.3	<3.5	15.2	<1.4	37.7	<0.60	<0.14	1.5
S08121130	0.231	63.3	<3.5	10.6	<1.4	56.7	<0.60	<0.14	3.64
S08190950	<0.11	48.9	<3.5	8.63	8.11	39	<0.60	0.6	2.77
S08191130	<0.11	51.1	5.98	2.7	<1.4	44.5	<0.60	<0.14	3.79
S08230945	0.266	47.8	11.5	1.09	28.5	43.5	<0.60	1.12	0.87
S08231107	<0.11	78.8	17.4	22.8	41.1	52.1	2.29	0.94	10.8
S08251250	<0.11	52.9	8.01	16.8	<1.4	33.9	<0.60	<0.14	4.72
S09011035	<0.11	46.3	<3.5	13.3	<1.4	38.7	<0.60	<0.14	4.22
S09011212	<0.11	60.2	<3.5	10.9	<1.4	49	<0.60	<0.14	5.12
S09061046	<0.11	78.9	17.5	<0.89	<1.4	54.4	<0.60	0.338	11.2
S09061225	0.28	45.8	<3.5	<0.89	<1.4	45.4	<0.60	0.348	14.4
S09081116	<0.11	97.9	25.1	<0.89	<1.4	35.6	<0.60	<0.14	31.7
S09081258	<0.11	107	29.6	<0.89	<1.4	57.7	<0.60	<0.14	45.6
S09131224	<0.11	50.1	<3.5	11.2	<1.4	38.7	<0.60	0.358	28
S09221138	5.13	104	<3.5	31.7	<1.4	69.6	<0.60	0.947	21.3
K10201120	<0.055	<0.77	<1.7	<0.43	<0.66	<0.67	<0.29	<0.067	0.607
A10201120	<0.096	<1.4	<3.0	<0.77	<1.2	<1.2	<0.52	<0.12	0.772
K10261107	0.256	46.8	<1.7	<0.43	<0.66	<0.67	<0.29	<0.067	1.41
A10261107	0.296	<1.4	<3.0	<0.77	<1.2	<1.2	<0.52	<0.12	1.1
K10261248	0.289	50.2	<1.7	<0.43	<0.66	<0.67	<0.29	<0.067	1.34
A10261248	0.436	1.94	<3.0	<0.77	<1.2	<1.2	<0.52	<0.12	1.43
K10281100	<0.055	<0.77	<1.7	<0.43	<0.66	<0.67	<0.29	<0.067	<0.42

EPA-CRF SYSTEMS RELIABILITY EPA-IRF CHLORINATED BENZENE STUDY

EXPERIMENTAL RESULTS (ORGANIC EMISSIONS, UG/MIN):

Sample ID	Cl5-EANE	1,3-DCBz	1,4–DCBz	CL6-EANE	1,2-DCBz	BzCL	1,3,5-TCBz	HC-1,3-BD	1,2,4-TCBz
A10281100	<0.098	<1.4	<3.0	<0.77	<1.2	<1.2	<0.52	<0.12	<0.75
K10281248	<0.055	<0.77	<1.7	<0.43	<0.66	<0.67	<0.29	<0.067	<0.42
A10281248	<0.098	<1.4	<3.0	<0.77	<1.2	<1.2	<0.52	<0.12	<0.75
K11011139	<0.055	<0.77	<1.7	<0.43	<0.66	<0.67	<0.29	<0.067	<0.42
A11011139	<0.098	<1.4	<3.0	<0.77	<1.2	<1.2	<0.52	<0.12	<0.75
K11011302	<0.055	<0.77	<1.7	<0.43	<0.66	<0.67	<0.29	<0.067	<0.42
A11011302	<0.092	<1.4	<3.0	<0.77	<1.2	<1.2	<0.52	<0.12	<0.75
K11031041	<0.055	<0.77	<1.7	<0.43	<0.66	<0.67	<0.29	<0.067	<0.42
A11031041	<0.098	<1.4	<3.0	<0.77	<1.2	<1.2	<0.52	<0.12	<0.75
K11031207	<0.098	<0.77	<1.7	<0.43	<0.66	<0.67	<0.29	<0.067	<0.42
A11031207	<0.055	<1.4	<3.0	<0.77	<1.2	<1.2	<0.52	<0.12	<0.75
K11091008	<0.055	<0.77	<1.7	0.482	<0.66	<0.67	<0.29	<0.067	<0.42
A11091008	0.371	<1.4	<3.0	<0.77	<1.2	<1.2	<0.52	<0.12	<0.75
K11091136	<0.055	<0.77	<1.7	<0.43	<0.66	<0.67	<0.29	<0.067	<0.42
A11091136	<0.098	<1.4	<3.0	<0.77	<1.2	<1.2	<0.52	<0.12	<0.75
K11111039	<0.055	0.735	<1.7	<0.43	<0.66	38.8	0.361	<0.067	0.976
A11111039	<0.098	<1.4	<3.0	<0.77	<1.2	21.3	<0.52	<0.12	<0.75
K11111210	<0.055	0.142	<1.7	<0.43	<0.66	39.3	<0.29	<0.067	<0.42
A11111210	<0.098	<1.4	<3.0	<0.77	<1.2	19.5	<0.52	<0.12	<0.75
K11181113	<0.055	<0.77	<1.7	<0.43	<0.66	<0.67	<0.29	<0.067	210
K11181125	<0.098	<0.77	<3.0	<0.77	<0.66	<0.67	<0.29	<0.067	682
K11181136	<0.055	<0.77	<1.7	<0.43	536	<0.67	15000	476	884000
A11181113	<0.098	<1.4	<3.0	<0.77	<1.2	<1.2	<0.52	<0.12	7.59
K11221045	0.337	10.3	<1.7	<0.43	<0.66	983	<0.29	0.0932	147
A11221045	<0.098	<1.4	<3.0	<0.77	<1.2	4680	<0.52	<0.12	1.2
K11221205	<0.055	4.55	<1.7	<0.43	<0.66	1030	1.02	<0.067	34.7
A11221205	<0.098	<1.4	<3.0	<0.77	12.1	4680	<0.52	<0.12	4.3
K12061309:1	13.4	<0.77	3.49	13.1	<0.66	1.29	<0.29	3.8	3.73
K12061309:2	<0.055	<0.77	4.42	<0.43	<0.66	1.31	<0.29	<0.067	3.3
K12061309:3	0.139	<0.77	4.52	<0.43	<0.66	1.33	<0.29	<0.067	3.41
K12131022	<0.055	<0.77	<1.7	<0.43	<0.66	<0.67	<0.29	<0.067	10.9
K12131040	<0.055	<0.77	2.34	<0.43	<0.66	2.51	<0.29	<0.067	<0.42
K12131224	<0.055	<0.77	2.71	<0.43	<0.66	1.03	<0.29	<0.067	0.65
K01131109	0.461	123	18	<0.43	67.7	126	23.9	<0.067	10600
K01131211	<0.055	129	108	5.88	64.4	36.9	22	<0.067	10100
K01131252	<0.055	67.5	20	<0.43	36.9	3.92	10	<0.067	3910
A01131109	22.6	<1.4	<3.0	71.8	<1.2	<1.2	<0.52	8.64	3.53

EPA-CRF SYSTEMS RELIABILITY EPA-IRF CHLORINATED BENZENE STUDY

EXPERIMENTAL RESULTS (ORGANIC EMISSIONS, UG/MIN):

Sample ID	CI5-EANE	1,3-DCBz	1,4–DCBz	CL6-EANE	1,2-DCBz	BzCL	1,3,5-TCBz	HC-1,3 BD	1,2,4-TCBz
K01241050	<0.055	<0.77	<1.7	<0.43	0.677	4.62	<0.29	<0.067	130
A01241050	<0.098	<1.4	5.71	<0.77	<1.2	<1.2	<0.52	<0.12	1.22
K01241225	<0.055	<0.77	<1.7	<0.43	<0.66	<0.67	<0.29	<0.067	102
A01241225	<0.098	<1.4	5.01	<0.77	<1.2	21.1	<0.52	<0.12	<0.75
K01241350	<0.055	2.67	4.45	<0.43	14.5	19.7	6.48	<0.067	3200
A01241350	<0.098	<1.4	12.2	<0.77	<1.2	9.03	<0.52	<0.12	2.59
K01261120	<0.055	<0.77	<1.1	0.462	<0.66	6.26	<0.29	<0.067	26.2
A01261120	<0.098	<1.4	<3.0	<0.77	<1.2	<1.2	<0.52	<0.12	7.59
K01261323	6.42	10.3	<1.7	<0.43	<0.66	983	2.58	0.0932	147
A01261323	0.489	<1.4	<3.0	<0.77	<1.2	4680	<0.52	<0.12	1.2
K01261444	<0.055	<1.4	<1.7	<0.43	<0.66	1030	1.02	<0.067	34.7
Sample ID	1,2,4,5-TCBz	1,2,3,4-TCBz	2-CLNaph	CL5-Bz	CL6-Bz	alpha-BHC	gamma-BHC	1,2,3,4-TCLNaph	Total
S08101045	3.15	3.27	<3.9	No Data	8.36	1.7	<0.64	<0.70	111.80
S08101300	3.16	<0.085	<3.9	No Data	27.6	8.06	11.5	28.7	197.07
S08121000	4.49	<0.085	<3.9	No Data	73.6	<0.35	1.68	<0.70	179.47
S08121130	5.11	1.97	<3.9	No Data	57.8	5	3.64	<0.70	207.99
S08190950	3.94	<0.085	<3.9	No Data	37.2	<0.35	2.33	2.71	154.19
S08191130	2.52	<0.085	<3.9	No Data	34.7	2.76	2.68	<0.70	150.73
S08230945	11.7	<0.085	<3.9	No Data	40.4	11.8	<0.64	<0.70	198.55
S08231107	5.97	<0.085	<3.9	No Data	35.5	<0.35	2.02	<0.70	269.72
S08251250	8.38	<0.085	<3.9	No Data	14.9	<0.35	<0.64	<0.70	139.61
S09011035	2.77	<0.085	<3.9	No Data	7.42	<0.35	<0.64	<0.70	112.71
S09011212	5.32	<0.085	<3.9	No Data	17.6	1.12	0.886	<0.70	150.15
S09061046	13.1	1.71	<3.9	No Data	23.7	<0.35	<0.64	<0.70	200.85
S09061225	10.5	<0.085	<3.9	No Data	22.8	1.78	<0.64	<0.70	141.31
S09081116	6.84	<0.085	<3.9	No Data	13.1	<0.35	<0.64	1.86	212.10
S09081258	14.5	<0.085	<3.9	No Data	21.5	<0.35	<0.64	<0.70	275.90
S09131224	5.29	<0.085	<3.9	No Data	21	<0.35	1.97	<0.70	156.62
S09221138	6	<0.085	<3.9	No Data	22.7	<0.35	1.3	<0.70	262.68
K10201120	<0.072	<0.041	<1.9	1.61	2.3	1.5	<0.31	2.58	8.60
A10201120	<0.13	<0.072	<3.3	0.268	0.675	0.55	<0.55	7.93	10.20
K10261107	<0.072	0.651	<1.9	12.5	<0.086	<0.17	0.326	<0.34	61.94
A10261107	0.306	<0.072	<3.3	1.87	6.48	<0.3	<0.55	<0.61	10.05
K10261248	<0.072	0.699	<1.9	13.3	<0.086	<0.17	<0.31	<0.34	65.83
A10261248	0.449	<0.072	<3.3	2.68	9.75	2.91	<0.55	<0.61	19.60
K10281100	<0.072	<0.041	<1.9	0.0857	<0.086	<0.17	<0.31	<0.34	0.09
A10281100	<0.13	<0.072	<3.3	0.0826	0.191	<0.3	<0.55	<0.61	0.27

EPA-CRF SYSTEMS RELIABILITY EPA-IRF CHLORINATED BENZENE STUDY

EXPERIMENTAL RESULTS (ORGANIC EMISSIONS, UG/MIN):

Sample ID	1,2,4,5-TCBz	1,2,3,4-TCBz	2-CLNaph	CL5-Bz	CL6-Bz	alpha-BHC	gamma-BHC	1,2,3,4-TCLNaph	Total
K10281248	<0.072	<0.041	<1.9	0.238	0.126	<0.17	<0.31	<0.34	3.64E-01
A10281248	<0.13	<0.072	<3.3	0.0081	0.2	<0.3	<0.55	<0.61	2.08E-01
K11011139	<0.072	<0.041	<1.9	0.415	0.135	<0.17	<0.31	<0.34	5.50E-01
A11011139	<0.13	<0.072	<3.3	0.108	<0.15	<0.3	<0.55	<0.61	1.08E-01
K11011302	<0.072	<0.041	<1.9	0.166	<0.086	<0.17	<0.31	<0.34	1.66E-01
A11011302	<0.13	<0.072	<3.3	<0.066	<0.15	<0.3	<0.55	<0.61	0.00E+00
K11031041	<0.072	<0.041	<1.9	0.146	<0.086	<0.17	<0.31	<0.34	1.46E-01
A11031041	<0.13	<0.072	<3.3	0.0671	<0.15	<0.3	<0.55	<0.61	6.71E-02
K11031207	<0.072	<0.041	<1.9	0.071	<0.086	<0.17	<0.31	<0.34	7.10E-02
A11031207	<0.13	<0.072	<3.3	<0.066	<0.15	<0.3	<0.55	<0.61	0.00E+00
K11091008	<0.072	<0.041	<1.9	0.107	<0.086	0.392	0.681	<0.34	1.66E+00
A11091008	<0.13	<0.072	<3.3	0.0909	<0.15	0.361	<0.55	<0.61	8.23E-01
K11091136	<0.072	<0.041	<1.9	0.0427	<0.086	<0.17	0.705	<0.34	7.48E-01
A11091136	<0.13	<0.072	<3.3	0.0815	<0.15	<0.3	<0.55	<0.61	8.15E-02
K11111039	1.98	0.912	<1.9	3.28	0.796	0.793	<0.31	<0.34	4.86E+01
A11111039	12.2	<0.072	<3.3	<0.066	<0.15	0.308	<0.55	<0.61	3.38E+01
K11111210	1.99	0.0644	<1.9	0.404	0.223	0.489	<0.31	<0.34	4.26E+01
A11111210	11.2	<0.072	<3.3	<0.066	<0.15	<0.3	<0.55	<0.61	3.07E+01
K11181113	<0.072	<0.041	15.7	0.505	<0.086	<0.17	<0.31	<0.34	2.26E+02
K11181125	<0.072	<0.041	26.2	5.06	<0.086	0.732	<0.31	<0.34	7.14E+02
K11181136	<0.072	7810	<1.9	57200	51300	57.6	4.44	2980	1.02E+06
A11181113	0.193	<0.072	<3.3	0.569	0.947	0.564	0.309	<0.61	1.02E+01
K11221045	<0.072	11.7	3.96	80.4	74.5	0.412	<0.31	2.82	1.31E+03
A11221045	<0.13	<0.072	1.16	0.103	0.485	<0.3	<0.55	<0.61	4.68E+03
K11221205	<0.072	4.32	4.16	20.6	15.9	0.298	<0.31	0.528	1.12E+03
A11221205	<0.13	0.234	1.16	3.23	3.9	<0.3	<0.55	<0.61	4.70E+03
K12061309:1	<0.072	0.366	<1.9	2.42	13.8	<0.17	<0.31	<0.34	5.54E+01
K12061309:2	<0.072	<0.041	<1.9	0.171	4.42	<0.17	<0.31	<0.34	1.36E+01
K12061309:3	0.211	<0.041	<1.9	0.356	6.01	<0.17	<0.31	<0.34	1.60E+01
K12131022	<0.072	<0.041	<1.9	0.037	<0.086	<0.17	<0.31	<0.34	1.09E+01
K12131040	<0.072	<0.041	<1.9	0.0832	<0.086	<0.17	<0.31	<0.34	4.93E+00
K12131224	0.192	0.3	<1.9	0.602	0.147	<0.17	<0.31	<0.34	5.63E+00
K01131109	<0.072	<0.041	<1.9	0.838	4.28	<0.17	0.866	<0.34	1.10E+04
K01131211	<0.072	<0.041	<1.9	0.037	9.51	<0.17	<0.31	<0.34	1.05E+04
K01131252	<0.072	0.453	<1.9	0.393	1.11	<0.17	<0.31	<0.34	4.05E+03
A01131109	<0.13	1.29	<3.3	6.44	16.2	<0.3	<0.55	<0.61	1.31E+02
K01241050	<0.072	0.0426	<1.9	<0.037	0.192	<0.17	<0.31	<0.34	1.36E+02

EPA-CRF SYSTEMS RELIABILITY EPA-IRF CHLORINATED BENZENE STUDY

EXPERIMENTAL RESULTS (ORGANIC EMISSIONS, UG/MIN):

Sample ID	1,2,4,5-TCBz	1,2,3,4-TCBz	2-CLNaph	CL5-Bz	CL6-Bz	alpha-BHC	gamma-BHC	1,2,3,4-TCLNaph	Total
A01241050	<0.13	0.411	<3.3	1.29	1.29	<0.3	<0.55	<0.61	9.92E+00
K01241225	<0.072	<0.041	<1.9	0.23	0.186	<0.17	<0.31	<0.34	1.02E+02
A01241225	<0.13	<0.072	<3.3	<0.066	<0.15	<0.3	<0.55	<0.61	2.61E+01
K01241350	<0.072	<0.041	<1.9	0.496	0.247	<0.17	<0.31	<0.34	3.25E+03
A01241350	<0.13	<0.072	<3.3	0.133	0.363	<0.3	<0.55	<0.61	2.43E+01
K01261120	<0.072	<0.041	<1.9	<0.037	0.156	<0.17	<0.31	<0.34	3.31E+01
A01261120	0.193	<0.072	<3.3	0.569	0.947	0.564	0.309	<0.61	1.02E+01
K01261323	<0.072	11.7	3.96	80.4	74.5	0.412	<0.31	2.82	1.32E+03
A01261323	<0.13	<0.072	1.16	0.103	0.485	<0.3	<0.55	<0.61	4.68E+03
K01261444	<0.072	4.32	4.16	20.6	15.9	0.298	<0.31	0.528	1.11E+03

Footnotes:

1. CL5-Pentachloroethane, 1,3-DCBz 1,3-Dichlorobenzene, 1,4-DCBz: 1,4-Dichlorobenzene, CL6-EANE: Hexachloroethane 1,2-DCBz: 1,2-Dichlorobenzene, BzCL: Benzyl chloride, 1,3,5-TCBz: 1,3,5-Trichlorobenzene, HC-1,3-BD: Hexachloro-1,3-butadiene, 1,2,4-TCBz: 1,2,4-Trichlorobenzene, 1,2,4,5-TCBz: 1,2,4,5-Tetrachlorobenzene 1,2,3,4-TCBz: 1,2,3,4-Tetrachlorobenzene, 2-CLNaph: 2-Chloronaphthalene, CL5-Bz: Pentachlorobenzene, CL6-Bz: Hexachlorobenzene, alpha-BHC: Alpha-hexachlorocyclohexane, gamma-BHC: Gamma-hexachlorocyclohexane, 1,2,3,4-TCNaph: 1.2.3.4-Tetrachloronaphthalene
2. K = kiln, A = afterburner, S = stack.

EMISSIONS ANALYSIS:

Sample ID	POHC Emissions (ug/min)	Total Emissions (ug/min)	PIC Emissions (ug/min)	% PIC Emissions (per POHC input)	% PIC Emissions (per waste input)	PIC:POHC Ratio
S08101045	8.36	120.16	111.8	0.0067	2.79E-04	13.37
S08101300	27.6	224.671	197.071	0.0118	4.92E-04	7.14
S08121000	73.6	253.07	179.47	0.0108	4.48E-04	2.44
S08121130	57.8	265.791	207.991	0.0125	5.19E-04	3.60
S08190950	37.2	191.39	154.19	0.0093	3.85E-04	4.14
S08191130	34.7	185.43	150.73	0.0090	3.76E-04	4.34
S08230945	-	197.676	197.676	NA	NA	-
S08231107	-	269.72	269.72	NA	NA	-
S08251250	-	139.61	139.61	NA	NA	-
S09011035	4.22	116.93	112.71	0.0068	2.82E-04	26.71
S09011212	5.12	155.266	150.146	0.0090	3.76E-04	29.33
S09061046	11.2	212.048	200.848	0.0024	5.58E-04	17.93
S09061225	14.4	155.708	141.308	0.0017	3.92E-04	9.81
S09081116	31.7	243.8	212.1	0.0013	6.83E-04	6.69
S09081258	45.6	321.5	275.9	0.0017	8.89E-04	6.05

EPA-CRF SYSTEMS RELIABILITY EPA-IRF CHLORINATED BENZENE STUDY

EMISSIONS ANALYSIS:

Sample ID	POHC Emissions (ug/min)	Total Emissions (ug/min)	PIC Emissions (ug/min)	% PIC Emissions (per POHC input)	% PIC Emissions (per waste input)	PIC:POHC Ratio
S09131224	-	156.618	156.618	NA	NA	-
S09221138	-	262.677	262.677	NA	NA	-
K10201120	-	8.597	8.597	NA	NA	-
A10201120	-	10.195	10.195	NA	NA	-
K10261107	-	61.943	61.943	NA	NA	-
A10261107	-	10.052	10.052	NA	NA	-
K10261248	-	65.828	65.828	NA	NA	-
A10261248	-	19.595	19.595	NA	NA	-
K10281100	-	0.0857	0.0857	NA	NA	-
A10281100	-	0.2736	0.2736	NA	NA	-
K10281248	-	0.364	0.364	NA	NA	-
A10281248	-	0.2081	0.2081	NA	NA	-
K11011139	-	0.55	0.55	NA	NA	-
A11011139	-	0.108	0.108	NA	NA	-
K11011302	-	0.166	0.166	NA	NA	-
A11011302	-	0	0	NA	NA	-
K11031041	-	0.146	0.146	NA	NA	-
A11031041	-	0.0671	0.0671	NA	NA	-
K11031207	-	0.071	0.071	NA	NA	-
A11031207	-	0	0	NA	NA	-
K11091008	-	1.662	1.662	NA	NA	-
A11091008	-	0.8229	0.8229	NA	NA	-
K11091136	-	0.7477	0.7477	NA	NA	-
A11091136	-	0.0815	0.0815	NA	NA	-
K11111039	0.976	49.609	48.633	0.0029	1.22E-04	49.83
A11111039	<0.75	33.808	33.808	0.0020	8.46E-05	-
K11111210	<0.42	42.6124	42.6124	0.0026	1.07E-04	-
A11111210	<0.75	30.7	30.7	0.0018	7.68E-05	-
K11181113	210	436.205	226.205	0.00005	3.39E-04	1.08
K11181125	682	1395.992	713.992	0.0011	1.07E-03	1.05
K11181136	884000	1903364.04	1019364.04	1.5290	1.53E+00	1.15
A11181113	7.59	17.762	10.172	0.000015	1.53E-05	1.34
K11221045	147	1461.5222	1314.5222	0.0789	3.29E-03	8.94
A11221045	1.2	4684.148	4682.948	0.2810	1.17E-02	3902.46
K11221205	34.7	1150.776	1116.076	0.0670	2.79E-03	32.16

EPA-CRF SYSTEMS RELIABILITY EPA-IRF CHLORINATED BENZENE STUDY

EMISSIONS ANALYSIS:

Sample ID	POHC Emissions (ug/min)	Total Emissions (ug/min)	PIC Emissions (ug/min)	% PIC Emissions (per POHC input)	% PIC Emissions (per waste input)	PIC:POHC Ratio
A11221205	4.3	4709.224	4704.924	0.2823	1.18E-02	1094.17
K12061309:1	3.73	59.126	55.396	0.0033	1.39E-04	14.85
K12061309:2	3.3	16.921	13.621	0.0008	3.41E-05	4.13
K12061309:3	3.41	19.386	15.976	0.0010	4.00E-05	4.69
K12131022	-	10.937	10.937	NA	NA	-
K12131040	-	4.9332	4.9332	NA	NA	-
K12131224	-	5.631	5.631	NA	NA	-
K01131109	10600	21565.045	10965.045	0.6579	2.74E-02	1.03
K01131211	10100	20575.727	10475.727	0.6285	2.62E-02	1.04
K01131252	3910	7960.276	4050.276	0.2430	1.01E-02	1.04
A01131109	3.53	134.03	130.5	0.0078	3.26E-04	36.97
K01241050	-	135.5316	135.5316	NA	NA	-
A01241050	-	9.921	9.921	NA	NA	-
K01241225	-	102.416	102.416	NA	NA	-
A01241225	-	26.11	26.11	NA	NA	-
K01241350	3200	6448.543	3248.543	0.1949	8.12E-03	1.02
A01241350	2.59	26.906	24.316	0.0015	6.08E-05	9.39
K01261120	-	33.078	33.078	NA	NA	-
A01261120	-	10.172	10.172	NA	NA	-
K01261323	-	1323.1852	1323.1852	NA	NA	-
A01261323	-	4683.437	4683.437	NA	NA	-
K01261444	15.9	1127.426	1111.526	0.0667	2.78E-03	69.91

EPA-CRF SYSTEMS RELIABILITY EPA-IRF CHLORINATED BENZENE STUDY

EMISSIONS ANALYSIS:

Sample ID	% Emissions (per fuel/waste input)	1,3-DCBz Emissions (ug/min)	BzCL Emissions (ug/min)	% 1,3-DiCLBZ Emissions (per CIPOHC input)	% BzCL Emissions (per CIPOHC input)
S08101045	2.88E-04	41.6	32.8	0.0025	0.0020
S08101300	5.39E-04	43.8	31.3	0.0026	0.0019
S08121000	6.07E-04	45.3	37.7	0.0027	0.0023
S08121130	6.37E-04	63.3	56.7	0.0038	0.0034
S08190950	8.07E-05	48.9	39	0.0029	0.0023
S08191130	7.65E-05	51.1	44.5	0.0031	0.0027
S08230945	1.01E-04	47.8	43.5	NA	NA
S08231107	1.34E-04	78.8	52.1	NA	NA
S08251250	2.95E-05	52.9	33.9	NA	NA
S09011035	2.47E-05	46.3	38.7	0.0028	0.0023
S09011212	3.87E-05	60.2	49	0.0036	0.0029
S09061046	6.87E-05	78.9	54.4	0.0009	0.0007
S09061225	3.25E-05	45.8	45.4	0.0005	0.0005
S09081116	5.65E-05	97.9	35.6	0.0006	0.0002
S09081258	7.93E-05	107	57.7	0.0006	0.0003
S09131224	3.07E-05	50.1	38.7	NA	NA
S09221138	4.78E-05	104	69.6	NA	NA
K10201120	NA	<0.77	<0.67	NA	NA
A10201120	NA	<1.4	<1.2	NA	NA
K10261107	NA	46.8	<0.67	NA	NA
A10261107	NA	<1.4	<1.2	NA	NA
K10261248	NA	50.2	<0.67	NA	NA
A10261248	NA	1.94	<1.2	NA	NA
K10281100	NA	<0.77	<0.67	NA	NA
A10281100	NA	<1.4	<1.2	NA	NA
K10281248	NA	<0.77	<0.67	NA	NA
A10281248	NA	<1.4	<1.2	NA	NA
K11011139	9.73E-08	<0.77	<0.67	NA	NA
A11011139	1.91E-08	<1.4	<1.2	NA	NA
K11011302	3.34E-08	<0.77	<0.67	NA	NA
A11011302	0.00E+00	<1.4	<1.2	NA	NA
K11031041	NA	<0.77	<0.67	NA	NA

EPA-CRF SYSTEMS RELIABILITY EPA-IRF CHLORINATED BENZENE STUDY

EMISSIONS ANALYSIS:

Sample ID	% Emissions (per fuel/waste input)	1,3-DCBz Emissions (ug/min)	BzCL Emissions (ug/min)	% 1,3-DiCLBZ Emissions (per CIPOHC input)	% BzCL Emissions (per CIPOHC input)
A11031041	NA	<1.4	<1.2	NA	NA
K11031207	NA	<0.77	<0.67	NA	NA
A11031207	NA	<1.4	<1.2	NA	NA
K11091008	NA	<0.77	<0.67	NA	NA
A11091008	NA	<1.4	<1.2	NA	NA
K11091136	NA	<0.77	<0.67	NA	NA
A11091136	NA	<1.4	<1.2	NA	NA
K11111039	9.51E-06	0.735	38.8	0.000044	0.0023
A11111039	6.48E-06	<1.4	21.3	NA	0.0013
K11111210	8.17E-06	0.142	39.3	0.000009	0.0024
A11111210	5.89E-06	<1.4	19.5	NA	0.0012
K11181113	3.27E-04	<0.77	<0.67	NA	0.00003
K11181125	1.05E-03	<0.77	<0.67	NA	NA
K11181136	1.43E+00	<0.77	<0.67	NA	NA
A11181113	1.33E-05	<1.4	<1.2	NA	NA
K11221045	3.51E-03	10.3	983	0.0006	0.0590
A11221045	1.12E-02	<1.4	4680	NA	0.2808
K11221205	2.76E-03	4.55	1030	0.0003	0.0618
A11221205	1.13E-02	<1.4	4680	NA	0.2808
K12061309:1	1.42E-04	<0.77	1.29	NA	0.0001
K12061309:2	4.06E-05	<0.77	1.31	NA	0.0001
K12061309:3	4.65E-05	<0.77	1.33	NA	0.0001
K12131022	2.96E-06	<0.77	<0.67	NA	NA
K12131040	1.33E-06	<0.77	2.51	NA	NA
K12131224	1.52E-06	<0.77	1.03	NA	NA
K01131109	6.95E-03	123	126	0.0074	0.0076
K01131211	6.63E-03	129	36.9	0.0077	0.0022
K01131252	2.56E-03	67.5	3.92	0.0041	0.0002
A01131109	4.32E-05	<1.4	<1.2	NA	NA
K01241050	NA	<0.77	4.62	NA	NA
A01241050	NA	<1.4	<1.2	NA	NA
K01241225	NA	<0.77	<0.67	NA	NA

EPA-CRF SYSTEMS RELIABILITY EPA-IRF CHLORINATED BENZENE STUDY

EMISSIONS ANALYSIS:

Sample ID	% Emissions (per fuel/waste input)	1,3-DCBz Emissions (ug/min)	BzCL Emissions (ug/min)	% 1,3-DiCLBZ Emissions (per ClPOHC input)	% BzCL Emissions (per ClPOHC input)
A01241225	NA	<1.4	21.1	NA	NA
K01241350	1.55E-02	2.67	19.7	0.0002	0.0012
A01241350	6.46E-05	<1.4	9.03	NA	0.0005
K01261120	1.34E-05	<0.77	6.26	NA	NA
A01261120	4.13E-06	<1.4	<1.2	NA	NA
K01261323	5.38E-04	10.3	983	NA	NA
A01261323	1.90E-03	<1.4	4680	NA	NA
K01261444	3.92E-04	<1.4	1030	NA	0.0618

QUALITATIVE PIC ANALYSIS OF SOOT-COVERED WATER-COOLED FEED LANCE:

Sample ID: M12081213

Compound	GC-FID	GC-ECD	GC/MS	Compound	GC-FID	GC-ECD	GC/MS
1,2-DCBZ	Y	Y	Y	Diisopropyl phthalate	Y	N	N
1,4-DCBZ	Y	Y	Y	Di-n-propyl phthalate	Y	N	N
Dodecane	Y	N	N	Anthracene	Y	N	
Indene	Y	N	N	Phenanthrene	Y	N	
1,3-DCBZ	Y	Y	Y	Docosane	Y	N	Y
1,3,5-TCBZ	Y	Y	N	9-Fluorenone	Y	Y	N
BENZYL CL	Y	Y	N	2-Methylanthracene	Y	N	N
Tridecane	Y	N	N	2,7-Dichlorodibenzo-p-dic	Y	N	N
1,2,4-TCBZ	Y	Y	Y	1-Methylphenanthrene	Y	N	N
œ,œ,œ-Trichlorotoluene	Y	N	N	Xanthone	Y	N	N
Tetradecane	Y	N	N	Tetracosane	Y	N	N
Compound	GC-FID	GC-ECD	GC/MS	Compound	GC-FID	GC-ECD	GC/MS
1,2,3-TCBz	Y	Y	N	1-Chloroanthracene	Y	Y	N
Naphthalene	Y	N	Y	2-Chloroanthracene	Y	N	N
œ,œ-Dichlorotoluene	Y	N	N	Anthraquinone	Y	Y	N
1,2,3,5-TCBz	Y	Y	N	Fluoranthene	Y	N	Y
1,2,4,5-TCBZ	Y	N	N	9,10-Dimethylanthracene	Y	N	N
2-Methylnaphthalene	Y	N	Y	9,10-Dichloroanthracene	Y	N	N
p-Chloroacetophenone	Y	N	N	Hexacosane	Y	N	N
Hexadecane	Y	N	N	Pyrene	Y	N	Y
Acenaphthene	Y	N	Y	Octacosane	Y	N	N
œ-Chloroacetophenone	Y	N	N	1-Chloroanthraquinone	Y	N	N
Acenaphthylene	Y	N	Y	bis-2-ethylhexylphthalate	Y	Y	Y
Cl6-Bz	Y	N	Y	Benzilbutylphthalate	Y	N	N

EPA-CRF SYSTEMS RELIABILITY EPA-IRF CHLORINATED BENZENE STUDY

QUALITATIVE PIC ANALYSIS OF SOOT-COVERED WATER-COOLED FEED LANCE:

Sample ID: M12081213

Compound	GC-FID	GC-ECD	GC/MS	Compound	GC-FID	GC-ECD	GC MS
Dibenzofuran	Y	N	Y	Benzo(c)phenathrene	Y	N	N
Dibenzo-p-dioxin	Y	N	N	Di-n-octylphthalate	Y	N	Y
Fluorene	Y	N	Y	1,8-Dichloroanthraquinon	Y	N	N
Nondecane	Y	N	N	Benz(a)anthracene-7,12-	Y	Y	N
Dimethylphthalate	Y	N	Y	Indeno(1,2,3-cd)pyrene	Y	N	N
Diethylphthalate	Y	N	Y	Octachlorodibenzo-p-diox	Y	Y	N
Diphenylacetylene	Y	N	N	Benzo(a)pyrene	Y	N	Y
Eicosane	Y	N	N	Perylene	Y	N	N
2-Chloro-1,4-naphthoquinone	Y	N	N	1,2,3,4-Dibenzanthracene	Y	N	N

KILN FAILURE EXPERIMENTS-HOT ZONE ANALYTICAL RESULTS (ug/min)

Kiln T, °C	815-788	760-732	704-677	815-788
AB T, °C	1093	1093	1093	1093
POHC Feed Rate (1,2,4-TCBz)	66666666.67	66666666.7	66666666.7	66666667
Compound	K11181113	K11181125	K11191136	A11181113
1,2-DCBz	<0.66	<0.66	536	<1.2
1,3,5-TCBz	<0.29	<0.29	1500	<0.52
HC-1,3-BD	<0.067	<0.067	476	<0.12
1,2,4-TCBz	210	682	884000	7.59
1,2,3,4-TCBz	<0.041	<0.041	7810	<0.072
CL5-Bz	0.505	5.06	57200	0.569
CL6-Bz	<0.086	<0.096	51300	0.947
1,2,3,4-TCNaph	<0.34	<0.34	2980	267
PIC:POHC Ratio	0.0024	0.0074	0.1378	35.3776
% PIC Emissions	0.000001	0.000008	0.182703	0.000403

EPA-CRF SYSTEMS RELIABILITY EPA-IRF CHLORINATED BENZENE STUDY

AFTERBURNER FAILURE EXPERIMENTS-HOT ZONE ANALYTICAL RESULTS (ug/min)

	NO POHC FEED				POHC FEED			
POHC Feed Rate	-	-	-	-	1666666.7	1666666.7	1666666.7	1666666.667
(HCB)	-	-	-	-				
Compound	K11091008	A11091008	K11091136	A11091136	K11111039	A11111039	K11111210	A11111210
CL5-EANE	<0.055	0.371	<0.055	<0.098	<0.055	<0.098	<0.055	<0.098
1,3-DCBz	<0.77	<1.4	<0.77	<1.4	0.735	<1.4	0.142	<1.4
1,4-DCBz	<1.7	<3.0	<1.7	<3.0	<1.7	<3.0	<1.7	<3.0
CL6-EANE	0.482	<0.77	<0.43	<0.77	<0.43	<0.77	<0.43	<0.77
1,2-DCBz	<0.66	<1.2	<0.66	<1.2	<0.66	<1.2	<0.66	<1.2
BzCL	<0.67	<1.2	<0.67	<1.2	38.8	21.3	39.1	19.5
1,3,5-TCBz	<0.29	<0.52	<0.29	<0.52	0.361	<0.52	<0.29	<0.52
HC-1,3-BD	<0.67	<0.12	<0.67	<0.12	<0.67	<0.12	<0.67	<0.12
1,2,4-TCBz	<0.42	<0.75	<0.42	<0.75	0.976	<0.75	<0.42	<0.75
1,2,4,5-TCBz	<0.072	<0.13	<0.072	<0.13	1.98	12.2	1.99	11.2
1,2,3,4-TCBz	<0.041	<0.072	<0.041	<0.072	0.912	<0.072	0.0644	<0.072
2-CLNaph	<1.9	<3.3	<1.9	<3.3	<1.9	<3.3	<1.9	<3.3
CL6-Bz	<0.086	<0.15	<0.086	<0.15	0.796	<0.15	0.223	<0.15
alpha-BHC	0.392	0.361	<0.17	<0.3	0.793	0.308	0.489	<0.3
gamma-BHC	0.681	<0.55	0.705	<0.55	<0.31	<0.55	<0.31	<0.55
1,2,3,4-TCNaph	<0.34	<0.61	<0.34	<0.61	<0.34	<0.61	<0.34	<0.61
PIC:POHC Ratio	-	-	-	-	55.9761	Infinite	187.3785	Infinite
% PIC Emissions	-	-	-	-	0.0027	0.0020	0.0025	0.0018

COMMENTS:

Benzyl chloride and the chlorinated benzenes were the major PICs observed. Toluene (part of the waste feed) and benzene were not measured. In the analysis of the gas-phase emissions, PIC:POHC ratios ranged from 1.02 to 3902 and % PIC emissions (per unit POHC) input ranged from 0.00005 to 1.53. A qualitative analysis of organics absorbed on a thin file of soot extracted from the feed lance indicated the presence of many compounds. However, agreement between GC-FID, GC-ECD, and GC-MS identifications was poor. Analysis of gas-phase emissions from simulated failure modes indicated that kiln flame out simulations produced much higher emissions than afterburner flame out simulations. The kiln tests indicated a dramatic increase in emissions resulted from a decrease in the kiln temperature below 700°C. Particulates emissions were not measured.

EPA-IRF PCB STUDY

SITE DESCRIPTION:

The liquid injection incinerator system at the EPA-CRF consists of a primary combustion chamber and an afterburner chamber. The hot combustion gas leaving the afterburner chamber is cooled in the liquid-sprayed quench chamber prior to particulate and HCl removal in downstream APCDs. The APCD system consists of Venturi, packed, and ionized scrubbers in series followed by additional particulate emission control in the carbon bed and high efficiency particulate filters. In this study, seven tests were performed over seven consecutive days with nominally identical incinerator operation. Total firing rate in the main combustor averaged 1.8 MBtu/hr. The PCB waste oil supplied 86% of the total heat input. Average gas temperatures in the main and afterburner chambers were 1240°C and 1026°C, respectively. Average excess air levels were 12%.

BULK FURNACE RESIDENCE TIME (CALCULATED):

~4.0 s

WASTE FEED COMPOSITION (POHCs ONLY):

Aroclor 1260 with small amounts of chlorinated benzenes.

AVERAGE FEED RATES (G/MIN):

	PCB	PROPANE	TOTAL
Test 1	800.0	98.91	898.91
Test 2	833.3	78.54	911.88
Test 3	833.3	78.54	911.88
Test 4	750.0	81.45	831.45
Test 5	866.7	84.36	951.03
Test 6	850.0	84.36	934.36
Test 7	750.0	84.36	834.36

CORRECTED AVERAGE PCB EMISSION RATES:

	Stack (ug/dscm)	Afterburner (ug/dscm)	Stack (ug/min)	Afterburner (ug/min)
Test 1	0.46	0.41	9.73	8.68
Test 3	0.15	0.27	3.35	6.03
Test 6	0.079	0.23	1.47	4.28
Average	0.23	0.30	4.85	6.33

APPENDIX D, cont

EPA-IRF PCB STUDY

CORRECTED AVERAGE PIC EMISSION RATES (UG/DSCM):

	Stack Test 1	Afterburner Test 1	Stack Test 3	Afterburner Test 3	Stack Test 6/7	Afterburner Test 6/7
Methylene chloride	98	145	170	114	58	BDL
1,1-Dichloroethene	2.6	5.9	1.9	8	0.18	2.2
1,1-Dichlorodichloroethane	BDL	BDL	19	2.4	BDL	BDL
trans-1,2-Dichloroethene	0.81	4.8	BDL	BDL	0.5	4.5
Chloroform	45	21	10	29	8	10
1,2-Dichloroethane/ 1-Butanone [1]	64	26	BDL	27	28	3.6
1,1,1-Trichloroethane	BDL	BDL	BDL	BDL	0.4	BDL
Carbon tetrachloride	4.7	BDL	3.1	BDL	BDL	BDL
Bromodichloromethane	BDL	BDL	11	1.8	13	11
1,2-Dichloropropane	4	3	1.5	BDL	BDL	BDL
trans-1,3-Dichloropropene	2	69	4.1	BDL	BDL	BDL
Trichloroethene	13	5.3	22	12	0.64	7.6
Benzene	53	0.77	BDL	BDL	20	1.7
1,1,2-Trichloroethane/ Chlorodibromomethane [1]	BDL	18	BDL	2	BDL	BDL
Bromoform	21	BDL	15	331	12	21
Tetrachloroethene/1,1,2,2-Tetrachloroethane [1]	7.1	BDL	BDL	BDL	8.8	BDL
Toluene/Heptane	5	1.5	4.6	5.8	14	4.4
Chlorobenzene						
1,3-Dichlorobenzene	BDL	BDL	BDL	BDL	BDL	BDL
1,2-Dichlorobenzene	0.59	0.05	BDL	BDL	BDL	6.3
1,4-Dichlorobenzene	BDL	1.1	BDL	BDL	BDL	0.58
1,2,3-Trichlorobenzene	0.03	0.36	BDL	BDL	0.01	0.29
1,2,4-Trichlorobenzene	0.41	0.97	BDL	BDL	0.078	0.52
1,2,3,4-Tetrachlorobenzene	0.004	0.85	0.048	0.082	0.004	0.68
1,2,3,5-Tetrachlorobenzene/ 1,2,4,5-Tetrachlorobenzene	BDL	0.13	BDL	BDL	0.003	0.11
Total Emissions:	321.704	304.14	262.398	533.352	163.694	74.71
Total PIC Emissions:	321.244	303.73	262.248	533.082	163.615	74.48
Total CLPIC Emissions:	242.244	301.46	242.648	196.282	117.615	47.38

Footnote:

1. Compounds elute at the same retention time.

EPA-IRF PCB STUDY

EMISSIONS ANALYSIS:

A. MINIMUM AVERAGE PIC:POHC RATIO [1]

	Afterburner	Stack
TEST 1	698.36	740.80
TEST 3	1748.32	1974.38
TEST 6	2071.08	323.83

1. Minimum value used when data greater than calibration range; below detection limit points taken as zero.

B. % EMISSIONS

	% PIC Emissions (per fuel/waste input)		% PIC Emissions (per POHC input)		% CLPIC Emissions (per POHC input)	
	AB	Stack	AB	Stack	AB	Stack
TEST 1	0.00076	0.00072	0.00085	0.00080	0.00064	0.00080
TEST 3	0.00064	0.00131	0.00070	0.00143	0.00065	0.00053
TEST 6	0.00033	0.00015	0.00036	0.00016	0.00026	0.00010

	%CHCL3 EMISSIONS (per POHC input)		% C2HCL3 EMISSIONS (per POHC input)	
	AB	Stack	AB	Stack
TEST 1	0.000056	0.000119	0.000014	0.000034
TEST 3	0.000074	0.000025	0.000030	0.000056
TEST 6	0.000025	0.000020	0.000019	0.000002

COMMENTS:

Although PCBs were destroyed to a DRE level of > 99.99999%, significant levels of organic emissions were produced. PIC:POHC ratios were very large at both the afterburner exit and the stack. Volatile emissions were much greater than semivolatile emissions, to the extent measured. Major volatile PICs were methylene chloride, chloroform, 1,2-dichloroethane/1-butanone (coeluting peaks) bromoform, and chlorobenzene. Benzene and toluene emissions were detected in much higher levels in the stack, presumably via contamination from the APCDs. The molecular weight range sampled and analyzed was not reported.

EPA-IRF SYNTHETIC MIXTURE STUDY

SITE DESCRIPTION:

A series of pilot-scale incineration tests was performed at the EPA's CRF to evaluate the use of SF6 injection as a possible DRE surrogate for use in hazardous waste incineration applications. In this study, a synthetic hazardous waste liquid containing tetrachloroethylene, toluene, chlorobenzene, and pentachlorobenzene as POHCs was incinerated in the liquid injection incineration system. SF6 was metered into the liquid feed line just prior to its introduction to the burner. A series of ten tests were conducted at different combinations of primary combustion temperature and excess air level. Combustor temperature was varied from 943°C to 1310°C and combustor exit flue gas O2 was varied from 1.3 to 9.2%. The specific objective of the test program was to compare SF6 DRE with other POHC DRE's under a range of incinerator operating conditions. A secondary objective was to extend the data base on PIC emissions from an incinerator, again as a function of incinerator operating conditions. We focus on these latter results in this analysis.

BULK FURNACE RESIDENCE TIME (CALCULATED):

~4.0 s

WASTE FEED COMPOSITION (POHCs ONLY):

Tetrachloroethylene, toluene, chlorobenzene, and pentachlorobenzene.

INCINERATOR OPERATING CONDITIONS:

	Waste Feedrate (g/min)	Propane Feedrate (g/min)	Total		Combustor Exit Temp. (°C) [1]	Combustor Exit O2 (%EA) [1]
Test 1	93.3	33.3	126.7	2.8	1030	2.3
Test 2	100.0	43.3	143.3	2.3	1114	3.3
Test 3	101.7	10.0	111.7	10.2	943	5.6
Test 4	103.3	98.3	201.7	1.1	1274	1.3
Test 5	88.3	85.0	173.3	1.0	1091	5.1
Test 6	98.3	20.0	118.3	4.9	945	8.2
Test 7	91.7	123.3	215.0	0.7	1310	4.5
Test 8	96.7	103.3	200.0	0.9	1077	9.2
Test 9	105.0	123.3	228.3	0.9	1175	8.0
Test 10	95.0	56.7	151.7	1.7	1105	4.7

Footnote:

1. Average values.

EPA-IRF SYNTHETIC MIXTURE STUDY

POHC INPUT CONCENTRATIONS (G/DSCM):

	Tetrachloroethylene	Toluene	Chlorobenzene	Pentachlorobenzene	Total
Test 1	1.1	8.7	1.3	1.1	12.2
Test 2	1.2	9.4	1.4	1.2	13.0
Test 3	1.2	9.5	1.4	1.2	13.3
Test 4	1.2	9.7	1.4	1.2	13.5
Test 5	1.0	8.3	1.2	1.0	11.5
Test 6	1.1	9.2	1.3	1.1	12.8
Test 7	1.1	8.6	1.2	1.1	12.0
Test 8	1.1	9.1	1.3	1.1	12.6
Test 9	1.2	9.8	1.4	1.2	13.7
Test 10	1.1	8.9	1.3	1.1	12.4
				Total:	127.0

CORRECTED AVERAGE POHC EMISSION RATES (UG/DSCM):

A. Secondary Combustor Exit

	Tetrachloroethylene	Toluene	Chlorobenzene	Pentachlorobenzene	Total
Test 1	4.6	5.9	1.0	8.4	19.9
Test 2	3.8	5.1	0.84	<3.6	9.74
Test 3	1	0.85	0.6	<2.8	2.45
Test 4	3.8	7	0.47	<3.6	11.27
Test 5	2.1	12	70	<3.4	84.1
Test 6	<0.26	1.9	<0.26	<2.9	1.9
Test 7	4.5	20	1.6	<3.3	26.1
Test 8	1.6	16	0.55	<3.3	18.15
Test 9	<0.24	<0.24	0.34	<3.6	0.34
Test 10	7.5	3.4	2.9	<3.5	13.8

B. Scrubber System Exit

	Tetrachloroethylene	Toluene	Chlorobenzene	Pentachlorobenzene	Total
Test 1	<0.27	<0.27	<0.27	Not reported	-
Test 2	<0.25	<0.25	<0.25	Not reported	-
Test 3	1.8	<0.27	0.48	Not reported	2.28
Test 4	<0.26	1.4	<0.26	Not reported	1.4
Test 5	0.39	0.34	<0.25	Not reported	0.73
Test 6	<0.25	0.65	<0.25	Not reported	0.65
Test 7	4	<0.26	0.93	Not reported	4.93
Test 8	0.4	3.9	0.3	Not reported	4.6
Test 9	<0.25	4.9	0.4	Not reported	5.3
Test 10	<0.25	<0.25	<0.25	Not reported	-

EPA-IRF SYNTHETIC MIXTURE STUDY

CORRECTED AVERAGE POHC EMISSION RATES (UG/DSCM):

C. Stack

	Tetrachloroethylene	Toluene	Chlorobenzene	Pentachlorobenzene	Total
Test 1	5.1	8.3	1.4	Not reported	14.8
Test 2	<0.25	<0.25	<0.25	Not reported	-
Test 3	-	-	-	Not reported	-
Test 4	2	11	1	Not reported	14
Test 5	-	-	-	Not reported	-
Test 6	-	-	-	Not reported	-
Test 7	-	-	-	Not reported	-
Test 8	-	-	-	Not reported	-
Test 9	-	-	-	Not reported	-
Test 10	-	-	-	Not reported	-
				Total:	28.8

BLANK CORRECTED AVERAGE PIC EMISSION RATES (UG/DSCM):

A. Secondary Chamber Exit

	Chloromethane	Dichloromethan	2-Butanone	Chloroform	Carbontetrachloride	Benzene	Total
Test 1	750	30	<0.3	4.4	3.3	4.2	791.9
Test 2	10	36	<0.3	5.1	2.1	2	55.2
Test 3	770	<0.3	<0.3	1.2	1.6	2.3	775.1
Test 4	7.6	<0.3	<0.3	<0.3	0.5	0.6	8.7
Test 5	720.	5.5	52	0.4	0.3	100	878.2
Test 6	190.	<0.3	<0.3	<0.3	0.7	1.2	191.9
Test 7	22.	8.3	<0.3	0.7	1.3	2.5	34.8
Test 8	180.	250	<0.3	<0.3	0.5	1	431.5
Test 9	89.	<0.3	<0.3	1.2	0.9	1.5	92.6
Test 10	97	25	2.4	15	1.4	1.1	141.9

B. Scrubber Exit

	Chloromethane	Dichloromethan	2-Butanone	Chloroform	Carbontetrachloride	Benzene	Total
Test 1	28	96	<0.3	9.9	7.5	6.2	147.6
Test 2	1	<0.3	3	3.4	11	7	25.4
Test 3	3.2	420	<0.3	5.1	8.6	6.1	443
Test 4	11	<0.3	19	1.7	0.3	10	42
Test 5	164	4.1	2.5	<0.3	<0.3	59	229.6
Test 6	2.1	16	<0.3	2	3.1	9.1	32.3
Test 7	4.5	8.8	9	2.1	0.8	28	53.2
Test 8	0.9	0.3	<0.3	<0.3	<0.3	31	32.2
Test 9	<0.5	130	11	4.8	0.4	31	177.2
Test 10	11	<0.3	3.1	5.8	0.4	12	32.3

EPA-IRF SYNTHETIC MIXTURE STUDY

BLANK CORRECTED AVERAGE PIC EMISSION RATES (UG/DSCM):

C. Stack

	Chloromethane	Dichloromethane	2-Butanone	Chloroform	Carbontetrachloride	Benzene	Total
Test 1	120	140	2.4	8.4	15	3.3	289.1
Test 2	0.6	<0.3	2.8	27	13	<0.3	43.4
Test 3	5.3	53	13	1.7	12	7.1	92.1
						Total:	424.6

EMISSIONS ANALYSIS:

A. Emissions Data

Secondary Combustor Exit

	Total Emissions (ug/dscm)	Total Emissions (ug/min)	PIC Emissions (ug/dscm)	CIPIC Emissions (ug/dscm)
Test 1	811.8	6223.80	791.9	787.7
Test 2	64.9	584.46	55.2	53.2
Test 3	777.6	5961.22	775.1	772.8
Test 4	20.0	173.07	8.7	8.1
Test 5	962.3	8179.55	878.2	726.2
Test 6	193.8	1582.70	191.9	190.7
Test 7	60.9	568.40	34.8	32.3
Test 8	449.7	3822.03	431.5	430.5
Test 9	92.9	851.95	92.6	91.1
Test 10	155.7	1245.60	141.9	138.4
Scrubber Exit				
Test 1	147.6	2140.20	147.6	141.4
Test 2	25.4	232.83	25.4	15.4
Test 3	445.28	3784.88	443	436.9
Test 4	43.4	868.00	42	13
Test 5	230.33	4184.33	229.6	168.1
Test 6	32.95	483.27	32.3	23.2
Test 7	58.13	823.51	53.2	16.2
Test 8	36.8	852.53	32.2	1.2
Test 9	182.5	2676.67	177.2	135.2
Test 10	32.3	274.55	32.3	17.2

EPA-IRF SYNTHETIC MIXTURE STUDY

EMISSIONS ANALYSIS:

A. Emissions Data

Stack

	Total Emissions (ug/dscm)	Total Emissions (ug/min)	PIC Emissions (ug/dscm)	CIPIC Emissions (ug/dscm)
Test 1	303.9	4406.55	289.1	283.4
Test 2	43.4	397.83	43.4	40.6
Test 3	92.1	782.85	92.1	72
Test 4	14.0	290.00		

B. PIC:POHC Ratios

	Secondary Combustor Exit	Scrubber Exit	Stack
Test 1	39.79	>189.2	19.53
Test 2	5.67	>35.3	No POHC data
Test 3	316.37	194.30	No POHC data
Test 4	0.77	30.00	No PIC data
Test 5	10.44	314.52	No PIC data
Test 6	101.00	49.69	No PIC data
Test 7	1.33	10.79	No PIC data
Test 8	23.77	7.00	No PIC data
Test 9	272.35	33.43	No PIC data
Test 10	10.28	>44.9	No PIC data
Average	78.18	91.39	19.53

C. % Emissions (per unit fuel/waste input)

	Secondary Combustor Exit	Scrubber Exit	Stack
Test 1	0.00491	0.00169	0.00348
Test 2	0.00041	0.00016	0.00028
Test 3	0.00534	0.00339	0.00070
Test 4	0.00009	0.00043	0.00014
Test 5	0.00472	0 00241	
Test 6	0.00134	0.00041	
Test 7	0.00026	0.00038	
Test 8	0.00191	0.00043	
Test 9	0.00037	0.00117	
Test 10	0.00082	0.00018	

EPA-IRF SYNTHETIC MIXTURE STUDY

EMISSIONS ANALYSIS:

D. % PIC Emissions (per unit POHC input)

	Secondary Combustor Exit	Scrubber Exit	Stack
Test 1	0.00121	0.00121	0.00237
Test 2	0.00019	0.00019	0.00033
Test 3	0.00336	0.00334	0.00069
Test 4	0.00032	0.00031	-
Test 5	0.00200	0.00199	-
Test 6	0.00026	0.00025	-
Test 7	0.00049	0.00044	-
Test 8	0.00029	0.00026	-
Test 9	0.00133	0.00129	-
Test 10	0.00026	0.00026	-

E. % CIPIC Emissions (per unit CIPOHC input)

	Secondary Combustor Exit	Scrubber Exit	Stack
Test 1	0.022945	0.004119	0.0083
Test 2	0.001446	0.000419	0.0011
Test 3	0.020666	0.011683	0.0019
Test 4	0.000213	0.000342	
Test 5	0.022351	0.005174	
Test 6	0.005272	0.000641	
Test 7	0.000958	0.000480	
Test 8	0.012107	0.000034	
Test 9	0.002359	0.003501	
Test 10	0.003961	0.000492	

F. % CH3Cl Emissions (per unit POHC input)

	Secondary Combustor Exit	Scrubber Exit	Stack
Test 1	0.00616	0.00023	0.000986
Test 2	0.00008	0.00001	0.000005
Test 3	0.00581	0.00002	0.000040
Test 4	0.00006	0.00008	
Test 5	0.00625	0.00142	
Test 6	0.00148	0.00002	
Test 7	0.00018	0.00004	
Test 8	0.00143	0.00001	
Test 9	0.00065	BDL	
Test 10	0.00078	0.00009	

EPA-IRF SYNTHETIC MIXTURE STUDY

EMISSIONS ANALYSIS:

G. % BZ Emissions (per unit POHC input)

	Secondary Combustor Exit	Scrubber Exit	Stack
Test 1	0.000035	0.000051	0.000027
Test 2	0.000015	0.000054	BDL
Test 3	0.000017	0.000046	0.000054
Test 4	0.000004	0.000074	
Test 5	0.000868	0.000512	
Test 6	0.000009	0.000071	
Test 7	0.000021	0.000234	
Test 8	0.000008	0.000246	
Test 9	0.000011	0.000226	
Test 10	0.000009	0.000097	

COMMENTS:

Chloromethane was the major PIC observed. Dichloromethane and benzene exhibited the largest emission rates of the other PICs detected. Analysis of the secondary combustor exit indicated that POHC:PIC ratios ranged 0.8 to 316, with 7 of 10 tests yielding ratios > 10.0. However, this identical set of data produced % PIC emissions (per unit POHC input) < 0.01. The average % PIC emissions decreased by a factor of 3 when analyzed at the scrubber exit and decreased by factor of 7 when analyzed in the stack.

APPENDIX E

EMISSIONS ANALYSIS - FULL SCALE INCINERATORS

A. AMERICAN CYANAMID - MRI STUDY [1]

Dependent Variables

Test No.	Total Emission Rate [2] (ug/min)	Total Emission Conc. (ug/dscm)	Total Emission Conc. (ug/dscm, corrected to 10% O_2)	% Emissions (per unit fuel/waste input)	Total PIC Emission Rate (ug/min)
2	26420.3	453.6	797.5	0.001050	26420.3
3	4307.8	77.7	134.4	0.000195	4307.8
4	10881.1	189.6	287.0	0.000340	10881.1
5	6799.0	120.8	202.6	0.000300	6799.0

[1] Arithmetic average of gas bag, VOST and MM5 data (not blank corrected).

[2] Includes volatile and semivolatile POHC and PIC emission data (not blank corrected); TUHC data excluded.

B. DOW CHEMICAL - MRI STUDY [1]

Dependent Variables

Test No.	Total Emission Rate [2] (ug/min)	Total Emission Conc. (ug/dscm)	Total Emission Conc. (ug/dscm, corrected to 10% O_2)	% Emissions (per unit fuel/waste input)	Total PIC Emission Rate (ug/min)
1	1609928.0	2590.0	2614.0	0.002200	908371.2
2	856278.9	1435.7	1580.8	0.001200	856278.9
3	1023637.7	1716.4	1990.2	0.001400	508902.4
4	2789776.3	4276.2	4805.2	0.003800	884010.3
5	44429883.8	62967.5	66635.5	0.059300	864207.5
6	24646827.2	35069.5	34750.7	0.033300	850777.4

[1] Arithmetic average of gas bag and VOST data (blank corrected).

[2] Includes volatile and semivolatile POHC and PIC emission data (blank corrected); TUHC data excluded.

[3] MRI GC data (blank corrected).

SPECIFIC PIC EMISSIONS (DOW STUDY):

	C_2H_3Cl	CH_2CL_2	1,2-dichloroethane	1,1,1-trichloroethane	ccl_4
1	3493.60	1970.81	3064.15	688.14	7933.78
2	BDL	1470.71	3184.92	4951.85	3044.86
3	BDL	1680.81	489.99	2640.99	2283.64
4	NA	3907.09	1339.99	1444.48	2914.41
5	NA	98682.41	289.85	781.14	4953.25
6	1316.66	91358.46	866.11	1167.06	4933.60
Ave	2405.13	33178.38	1539.17	1945.61	4343.92
Ge ave	2144.73	7454.56	1082.45	1509.93	3972.34

APPENDIX E, cont

EMISSIONS ANALYSIS - FULL SCALE INCINERATORS

Dependent Variables

Total PIC Emission Conc. (ug/dscm)	Total PIC Emission Conc. (ug/dscm, corrected to 10% O2)	% PIC Emissions (per unit POHC input)	% PIC Emissions (per unit waste input)	Total CIPIC Emission Rate (ug/min)
453.6	797.5	0.001871	0.001051	2206.3
77.7	134.4	0.000318	0.000195	1475.5
189.6	287.0	0.000526	0.000344	581.5
120.8	202.6	0.000561	0.000303	663.0

Dependent Variables

Total PIC Emission Conc. (ug/dscm)	Total PIC Emission Concentration (ug/dscm, corrected to 10% O2)	% PIC Emissions (per unit PCHC input)	% PIC Emissions (per unit waste input)	Total CIPIC Emission Rate (ug/min)
1433.5	1446.7	0.089601	0.001296	876192.4
1426.6	1570.7	0.084463	0.001222	830502.5
835.3	968.6	0.050198	0.000726	492143.8
1349.7	1516.6	0.089193	0.001257	831796.6
1181.6	1250.5	0.087195	0.001229	811003.5
1202.9	1192.0	0.085840	0.001210	829874.2

dichlorobromomethane	chlorodibromomethane	bromoform	PCE	chorobenzene
18589.19	6984.36	7821.33	1710.56	290.42
22699.83	4639.30	625.35	1230.91	278.65
23105.18	4123.82	BDL	1230.91	278.65
30152.25	2819.40	78668.34	897.66	609.63
959.15	1219.72	3699.28	BDL	1318.68
10031.06	1214.88	736.92	BDL	1641.81
17589.45	3500.25	15258.54	1267.51	736.31
11892.07	2869.49	4019.28	1235.02	556.69

EMISSIONS ANALYSIS - FULL SCALE INCINERATORS

Dependent Variables

Total CIPIC Emission Conc. (ug/dscm)	Total CIPIC Emission Conc. (ug/dscm, corrected to 10% O2)	% CIPIC Emissions (per unit POHC input)	% CIPIC Emission (per unit Waste input)	PIC:POHC
37.9	66.6	0.000156	0.000088	88.0
26.6	46.0	0.000109	0.000067	14.0
10.1	15.3	0.000028	0.000018	3.6
11.8	19.8	0.000055	0.000030	22.0

Dependent Variables

Total CIPIC Emission Conc. (ug/dscm)	Total CIPIC Emission Conc. (ug/dscm, corrected to 10% O2)	% CIPIC Emissions (per unit CIPOHC input)	% CIPIC Emission (per unit Waste input)	PIC:POHC Ratio
1409.6	1422.6	0.086427	0.001250	2.00E+07
1392.5	1533.2	0.081920	0.001185	1.00E+08
825.2	956.9	0.048545	0.000702	4.00E+07
1275.0	1432.7	0.083925	0.001183	1.00E+07
1149.4	1216.3	0.081827	0.001154	8.00E+06
1180.8	1170.1	0.083731	0.001180	3.00E+07

APPENDIX E, cont

EMISSIONS ANALYSIS - FULL SCALE INCINERATORS

Dependent Variables

Chloroform Emission Rate (ug/min)	Chloroform Emission Conc. (ug/dscm)	Chloroform Emission Conc. (ug/dscm, corrected to 10% O2)	% Chloroform Emissions (per unit POHC input)	% Chloroform Emissions (per unit waste input)
1280.00	21.98	38.64	0.000091	0.000051
203.00	3.66	6.34	0.000015	0.000009
132.33	2.31	3.49	0.000006	0.000004
20.00	0.36	0.60	0.000002	0.000001

Dependent Variables

Toluene Emission Rate (ug/min)	Toluene Emission Conc. (ug/dscm)	Toluene Emission Conc. (ug/dscm, corrected to 10% O2)	% Toluene Emissions (per unit POHC input)	% Toluene Emissions (per unit waste input)
17322.26	27.87	28.13	0.001709	0.000025
5464.11	9.16	10.09	0.000539	0.000008
10700.55	17.94	20.80	0.001055	0.000015
3486.69	5.34	6.01	0.000344	0.000005
30437.42	43.14	45.65	0.003002	0.000043
5365.78	7.63	7.57	0.000529	0.000008

APPENDIX E cont

EMISSIONS ANALYSIS - FULL SCALE INCINERATORS

Dependent Variables

Benzene Emission Rate (ug/min)	Benzene Emission Conc. (ug/dscm)	Benzene Emission Conc. (ug/dscm, corrected to 10% O2)	% Benzene Emissions (per unit POHC input)
1010.00	17.34	30.49	0.000072
567.50	10.24	17.71	0.000042
223.33	3.89	5.89	0.000011
570.00	10.13	16.98	0.000047

Dependent Variables

Benzene Emission Rate (ug/min)	Benzene Emission Conc. (ug/dscm)	Benzene Emission Conc. (ug/dscm, corrected to 10% O2)	% Benzene Emissions (per unit POHC input)
14856.50	23.90	24.12	0.001465
20312.25	34.06	37.50	0.002004
6058.04	10.16	11.78	0.000598
48726.97	74.69	83.93	0.004916
22766.58	32.27	34.15	0.002297
15537.42	22.11	21.91	0.001569

APPENDIX E, cont.

EMISSIONS ANALYSIS - FULL SCALE INCINERATORS

	Dependent Variables		
% Benzene Emissions (per unit waste input)	Toluene Emission Rate (ug/min)	Toluene Emission Conc. (ug/dscm)	Toluene Emission Conc. (ug/dscm, corrected to 10% O2)
0.000040	1494.00	25.65	45.10
0.000026	364.75	6.58	11.38
0.000007	366.33	6.38	9.66
0.000025	1200.00	21.32	35.76

	Dependent Variables		
% Benzene Emissions (per unit waste input)	Chloromethane Emission Rate [3] (ug/min)	Chloromethane Emission Conc. (ug/dscm)	Chloromethane Emission Conc. (ug/dscm, corrected to 10% O2)
0.000021	291455.60	468.88	473.22
0.000029	383453.03	642.95	707.89
0.000009	127199.00	213.28	247.31
0.000069	272464.98	417.63	469.30
0.000032	285167.30	404.15	427.69
0.000022	456236.76	649.17	643.27

APPENDIX E, cont.

EMISSIONS ANALYSIS - INCIN.

Dependent Variables

% Toluene Emissions (per unit POHC input)	% Toluene Emissions (per unit waste input)	1,1,1-Trichloroethane Emission Rate (ug/min)	1,1,1-Trichloroethane Emission Conc. (ug/dscm)
0.000106	0.000059	58.33	1.00
0.000027	0.000016	6.00	0.11
0.000018	0.000012	132.33	2.31
0.000099	0.000053	20.00	0.36

Dependent Variables

% Chloromethane Emissions (per unit POHC input)	% Chloromethane Emissions (per unit waste input)	Chloroform Emission Rate (ug/min)	Chloroform Emission Conc. (ug/dscm)
0.0287	0.0004	49609.35	79.81
0.0378	0.0005	89648.08	150.32
0.0125	0.0002	76507.48	128.28
0.0275	0.0004	233185.63	357.43
0.0288	0.0004	82915.32	117.51
0.0460	0.0006	61939.72	88.13

EMISSIONS ANALYSIS - INCIN.

Dependent Variables

1,1,1-Trichloroethane Emission Conc. (ug/dscm, corrected to 10% O2)	% 1,1,1-Trichloroethane Emissions (per unit POHC input)	% 1,1,1-Trichloroethane Emissions (per unit waste input)	Carbon Tet Emission Rate (ug/min)
1.76	0.000004	0.000002	44.33
0.19	0.000000	0.000000	175.25
3.49	0.000006	0.000004	20.67
0.60	0.000002	0.000001	51.00

Dependent Variables

Chloroform Emission Conc. (ug/dscm, corrected to 10% O2)	% Chloroform Emissions (per unit POHC input)	% Chloroform Emissions (per unit waste input)	T, Primary Chamber (°C)
80.55	0.0049	0.0001	843
165.50	0.0088	0.0001	752
148.75	0.0075	0.0001	781
401.65	0.0235	0.0003	782
124.36	0.0084	0.0001	740
87.33	0.0062	0.0001	797

APPENDIX E, cont

EMISSIONS ANALYSIS - INCIN.

Dependent Variables

Carbon Tet Emission Conc. (ug/dscm)	Carbon Tet Emission Conc. (ug/dscm, corrected to 10% O2)	% Carbon Tet Emissions (per unit POHC input)	% Carbon Tet Emissions (per unit waste input)
0.76	1.34	0.000003	0.000002
3.16	5.47	0.000013	0.000008
0.36	0.55	0.000001	0.000001
0.91	1.52	0.000004	0.000002

Independent Variables

T, Secondary Chamber (°C)	T, APCD (°C)	T, Stack (°C)	R.T., Primary Chamber (s)
1014	79	73	NA
948	78	71	NA
931	77	68	NA
969	78	71	NA
972	80	74	NA
1011	82	75	NA

EMISSIONS ANALYSIS - INCIN.

Dependent Variables

Trichloroethylene Emission Rate (ug/min)	Trichloroethylene Emission Conc. (ug/dscm)	Trichloroethylene Emission Conc. (ug/dscm, corrected to 10% O2)	% Trichloroethylene Emissions (per unit POHC input)
503.33	8.64	15.19	0.000036
945.25	17.05	29.50	0.000070
204.67	3.57	5.40	0.000010
420.00	7.46	12.51	0.000035

Independent Variables

R.T., Secondary Chamber (s)	R.T., Total (s)	Flue Gas Flow Rate cfm	O2 Conc., Primary Chamber (%)
NA	NA	22200	NA
NA	NA	21300	NA
NA	NA	21300	NA
NA	NA	23300	NA
NA	NA	25200	NA
NA	NA	25100	NA

APPENDIX E, cont

EMISSIONS ANALYSIS - INCIN.

Dependent Variables

% Trichloroethylene Emissions (per unit waste input)	Tetrachloroethylene Emission Rate (ug/min)	Tetrachloroethylene Emission Conc. (ug/dscm)	Tetrachloroethylene Emission Conc. (ug/dscm, corrected to 10% O2)
0.000020	42.67	0.73	1.29
0.000043	23.00	0.41	0.72
0.000006	50.80	0.89	1.34
0.000019	62.00	1.10	1.85

Independent Variables

O2 Conc., Secondary Chamber (%)	O2 Conc. Stack (%)	CO (ppm)	(average values, corrected to 3% O2) Cold THC (ppm, relative to CH4)
NA	10.1	3.31	0.0000
NA	11	3.62	0.0000
NA	11.5	3.81	0.0000
NA	11.2	27.68	0.0000
NA	10.6	15.64	99.0000
NA	9.9	39.05	60.0000

EMISSIONS ANALYSIS - INCIN.

Dependent Variables

% Tetrachloroethylene Emissions (per unit POHC input)	% Tetrachloroethylene Emissions (per unit waste input)	Chlorobenzene Emission Rate (ug/min)	Chlorobenzene Emission Conc. (ug/dscm)
0.000003	0.000002	277.67	4.77
0.000002	0.000001	123.00	2.22
0.000002	0.000002	40.67	0.71
0.000005	0.000003	90.00	1.60

Independent Variables

Hot THC (ppm, rel to CH4)	NOx (g/dscm)	Particulates (g/sec)	Particulate entering APCD (g/dscm)
7.6	NA	9.88	NA
6.8	NA	8.47	NA
6.2	NA	5.37	NA
8.8	NA	7.24	NA
145	NA	16.65	NA
106	NA	24.95	NA

APPENDIX E, cont

EMISSIONS ANALYSIS - INCIN.

Dependent Variables

Chlorobenzene Emission Conc. (ug/dscm, corrected to 10% O2)	% Chlorobenzene Emissions (per unit POHC input)	% Chlorobenzene Emissions (per unit waste input)	Naphthalene Emission Rate (ug/min)
8.38	0.000020	0.000011	13010.00
3.84	0.000009	0.000006	1500.00
1.07	0.000002	0.000001	9110.00
2.68	0.000007	0.000004	4006.00

Independent Variables

APCD Efficiency (%)	Cl Feed Rate (g/min)	HCl Stack Conc. (g/sec)	Cl in Scrubber inlet (mg/L)
99.98	491.21	0.0183	0.0536
99.95	491.21	0.0206	0.0566
99.96	491.21	0.0206	0.0621
99.92	425.96	0.0306	0.0601
99.96	425.96	0.0225	0.0004
99.96	425.96	0.0306	0.0075

EMISSIONS ANALYSIS - INCIN.

Dependent Variables

Naphthalene Emission Conc. (ug/dscm)	Naphthalene Emission Conc. (ug/dscm, corrected to 10% O2)	% Naphthalene Emissions (per unit POHC input)	% Naphthalene Emissions (per unit waste input)	o-Nitrophenol Emission Rate (ug/min)
223.39	392.73	0.000922	0.000518	8700.00
27.06	46.81	0.000111	0.000068	400.00
158.71	240.27	0.000440	0.000288	600.00
71.18	119.36	0.000331	0.000178	360.00

Independent Variables

Cl in Scrubber outlet (mg/L)	Cl out/Cl in (scrubber)	Waste Load (Mbtu/hr)	Waste Load (lb./hr.)	Waste:Fuel Feed Ratios
0.0073	0.1366	43.9	9270	24.92
0.0050	0.0880	43.9	9270	22.39
0.0028	0.0446	39.1	9270	21.91
0.0020	0.0339	38.2	9300	16.85
0.0007	1.6905	39	9300	15.12
0.0006	0.0811	45.2	9300	17.48

APPENDIX E, cont

EMISSIONS ANALYSIS - INCIN.

Dependent Variables

o-Nitrophenol Emission Conc. (ug/dscm)	o-Nitrophenol Emission Conc. (ug/dscm, corrected to 10% O2)	% o-Nitrophenol Emissions (per unit POHC input)	% o-Nitrophenol Emissions (per unit waste input)	T, Primary Chamber (°C)
149.38	262.62	0.000616	0.000346	NA
7.22	12.48	0.000030	0.000018	NA
10.45	15.82	0.000029	0.000019	NA
5.40	10.73	0.000030	0.000016	NA

No. of POHCs
1
1
1
1
1
1

APPENDIX E, cont

EMISSIONS ANALYSIS - INCIN.

Independent Variables

T, Secondary Chamber (°C)	T, APCD (°C)	T, Stack (°C)	R.T., Primary Chamber (s)	R.T., Secondary Chamber (s)	R.T., Total (calculated, s)	Flue Gas Flow Rate dscfm
NA	NA	671	NA	NA	0.21	2080
NA	NA	629	NA	NA	0.24	1980
NA	NA	679	NA	NA	0.23	2050
NA	NA	648	NA	NA	0.21	2010

APPENDIX E, cont

EMISSIONS ANALYSIS - INCIN.

Independent Variables			(average values, corrected to 3% O2)		
O2 Conc., Primary Chamber (%)	O2 Conc., Secondary Chamber (%)	O2 Conc. Stack (%)	CO (ppm)	Cold THC (as propane, ppm)	Hot THC (ppm)
NA	NA	14.7	30.60	<1	NA
NA	NA	14.6	NA	<1	NA
NA	NA	13.7	10.80	<1	NA
NA	NA	14.4	14.30	<1	NA

APPENDIX E, cont

EMISSIONS ANALYSIS - INCIN.

Independent Variables

NOx (ppm)	Particulates (g/sec)	Particulate entering APCD (g/dscm)	APCD Efficiency (%)	Cl Feed Rate (g/min)	HCl Stack Conc. (g/sec)	Cl in Scrubber inlet (mg/L)
NA	0.0750	0.0770	NA	0.37644	0.00056	NA
NA	0.0667	0.0717	NA	0.44213	0.00083	NA
NA	0.0072	0.0076	NA	0.59991	0.00083	NA
NA	0.1778	0.1885	NA	0.29151	0.00083	NA

EMISSIONS ANALYSIS - INCIN.

Independent Variables

Cl in Scrubber outlet (mg/L)	Cl out/Cl in (scrubber)	Waste Load (Mbtu/hr)	Waste Load (lb./hr.)	Waste:Fuel Feed Ratios	No. of POHCs
NA	NA	4.83	332.40	No fuel	5
NA	NA	4.24	292.80	No fuel	5
NA	NA	4.51	418.20	No fuel	5
NA	NA	4.29	297.00	No fuel	5

EMISSIONS ANALYSIS - FULL SCALE INCINERATORS

C. ZAPATA - MRI STUDY [1]

Dependent Variables

Test No.	Total Emission Rate (ug/min)	Total Emission Conc. (ug/dscm)	Total Emission Conc. (ug/dscm, corrected to 10% O2)	% Emissions (per unit fuel/waste input)	Total PIC Emission Rate (ug/min)
1	5756.0	274.5	393.6	0.000900	836.0
2	2981.0	139.2	172.4	0.000400	1086.0
3	3053.0	139.8	157.1	0.000400	338.0
4	2299.0	105.9	117.8	0.000300	739.0

[1] Arithmetic average of gas bag, VOST and MM5 data (not blank corrected).

[2] Includes volatile and semivolatile POHC and PIC emission data (not blank corrected); TUHC data excluded.

[3] Toluene was a POHC in this study.

D. TWI INCINERATOR - MRI STUDY [1]

1. OPTIMUM CONDITIONS

Dependent Variables

Test No.	Total Emission Rate [2] (ug/min)	Total Emission Conc. (ug/dscm)	Total Emission Conc. (ug/dscm, corrected to 10% O2)	% Emissions (per unit fuel/waste input)	Total PIC Emission Rate (ug/min)
1	15351.3	143.9	184.5	0.000095	3691.3
2	93510.0	662.6	914.3	0.000662	5410.0
3	106418.0	745.2	1054.9	0.000821	13880.0
4	59960.0	359.3	738.9	0.000678	3660.0

[1] Arithmetic average of gas bag, VOST and MM5 data (not blank corrected).

[2] Includes volatile and semivolatile POHC and PIC emission data (not blank corrected); TUHC data excluded.

2. FAILURE MODE CONDITIONS

Dependent Variables

Test No.	Total Emission Rate [2] (ug/min)	Total Emission Conc. (ug/dscm)	Total Emission Conc. (ug/dscm, corrected to 10% O2)	% Emissions [3] (per unit waste input)	Total PIC Emission Rate (ug/min)
1	218070.0	1331.3	1860.4	0.001896	41470.0
2	138790.0	838.7	1075.5	0.001006	41620.0
3	28398.0	159.5	259.4	0.000307	2800.0
4	9737.0	54.9	80.8	0.000086	770.0

[1] Arithmetic average of gas bag, VOST and MM5 data (not blank corrected).

[2] Includes volatile and semivolatile POHC and PIC emission data (not blank corrected); TUHC data excluded.

[3] Fuel feedrate not recorded.

APPENDIX F, cont.

EMISSIONS ANALYSIS - FULL SCALE INCINERATORS

Dependent Variables

Total PIC Emission Conc. (ug/dscm)	Total PIC Emission Conc. (ug/dscm, corrected to 10% O2)	% PIC Emissions (per unit POHC input)	% PIC Emissions (per unit waste input)	Total CIPIC Emission Rate (ug/min)
39.9	57.2	0.000059	0.000127	116.0
50.7	62.8	0.000080	0.000142	115.5
15.5	17.4	0.000016	0.000043	98.0
34.1	37.9	0.000061	0.000096	79.0

Dependent Variables

Total PIC Emission Conc. (ug/dscm)	Total PIC Emission Conc. (ug/dscm, corrected to 10% O2)	% PIC Emissions (per unit POHC input)	% PIC Emissions (per unit waste input)	Total CIPIC Emission Rate (ug/min)
34.6	44.4	0.000236	0.00002	93.3
38.3	52.9	0.000650	0.00004	1710.0
97.2	137.6	0.001061	0.00013	3300.0
21.9	45.1	0.000536	0.00005	2060.0

Dependent Variables

Total PIC Emission Conc. (ug/dscm)	Total PIC Emission Conc. (ug/dscm, corrected to 10% O2)	% PIC Emissions (per unit POHC input)	% PIC Emissions (per unit waste input)	Total CIPIC Emission Rate (ug/min)
253.2	353.8	0.002810	0.000361	2470.0
251.5	322.5	0.002524	0.000302	1620.0
15.7	25.6	0.000191	0.000030	0.0
4.3	6.4	0.000048	0.000007	NA

APPENDIX F, cont

EMISSIONS ANALYSIS - FULL SCALE INCINERATORS

Dependent Variables

Total CIPIC Emission Conc. (ug/dscm)	Total CIPIC Emission Conc. (ug/dscm, corrected to 10% O2)	% CIPIC Emissions (per unit CIPOHC input)	% CIPIC Emission (per unit Waste input)	PIC:POHC
5.5	7.9	0.000008	0.000018	0.17
5.4	6.7	0.000009	0.000015	0.70
4.5	5.0	0.000005	0.000013	0.33
3.6	4.0	0.000007	0.000010	0.50

Dependent Variables

Total CIPIC Emission Conc. (ug/dscm)	Total CIPIC Emission Conc. (ug/dscm, corrected to 10% O2)	% CIPIC Emissions (per unit CIPOHC input)	% CIPIC Emission (per unit ClWaste input)	PIC:POHC
0.9	1.1	0.000070	0.000070	0.32
12.1	16.7	0.001173	0.001173	0.06
23.1	32.7	0.002360	0.002360	0.15
12.3	25.4	0.001444	0.001444	0.07

Dependent Variables

Total CIPIC Emission Conc. (ug/dscm)	Total CIPIC Emission Conc. (ug/dscm, corrected to 10% O2)	% CIPIC Emissions (per unit CIPOHC input)	% CIPIC Emission (per unit ClWaste input)	PIC:POHC
15.1	21.1	0.001464	0.001464	0.23
9.8	12.6	0.002161	0.002161	0.43
0.0	0.0	0.000000	0.000000	0.11
NA	NA	NA	NA	0.09

EMISSIONS ANALYSIS - FULL SCALE INCINERATORS

Dependent Variables

Toluene Emission Rate [3] (ug/min)	Toluene Emission Conc. (ug/dscm)	Toluene Emission Conc. (ug/dscm, corrected to 10% O2)	% Toluene Emissions (per unit POHC input)	% Toluene Emissions (per unit waste input)
380.00	18.12	25.99	0.001607	0.000058
600.00	28.01	34.70	0.001992	0.000079
400.00	18.32	20.58	0.001384	0.000051
530.00	24.42	27.17	0.001338	0.000069

Dependent Variables

Naph Emission Rate (ug/min)	Naph Emission Conc. (ug/dscm)	Naph Emission Conc. (ug/dscm, corrected to 10% O2)	% Naph Emissions (per unit POHC input)	% Naph Emissions (per unit waste input)
3500.0	32.8	42.1	0.000223	0.000023
1700.0	12.0	16.6	0.000204	0.000013
580.0	4.1	5.7	0.000044	0.000006
NA	NA	NA	NA	NA

Independent Variables

T, Primary Chamber (°C)	T, Secondary Chamber (°C)	T, Quench (°C)	T, Stack (°C)	R.T., Primary Chamber (s)
1220	1150	82	67	NA
1110	1120	84	66	NA
1120	1160	79	59	NA
1120	1170	82	62	NA

EMISSIONS ANALYSIS - FULL SCALE INCINERATORS

Dependent Variables

Chloroform Emission Rate (ug/min)	Chloroform Emission Conc. (ug/dscm)	Chloroform Emission Conc. (ug/dscm, corrected to 10% O2)	% Chloroform Emissions (per unit POHC input)
36.00	1.72	2.46	0.000152
50.75	2.37	2.93	0.000169
55.50	2.54	2.86	0.000192
31.00	1.43	1.59	0.000078

Independent Variables

T, Primary Chamber (°C)	T, Secondary Chamber (°C)	T, Quench (°C)	T, Stack (°C)
1140	1110	80	66
1110	1090	79	59
1130	1110	79	62
988	965	73	52

Independent Variables

R.T., Secondary Chamber (s)	R.T., Both Chambers (s)	Flue Gas Flow Rate (dscfm)	O2 Conc., Primary Chamber Outlet (%)
NA	3.0	5850	NA
NA	3.0	5910	NA
NA	2.8	6360	NA
NA	2.8	6340	NA

EMISSIONS ANALYSIS - INCIN.

Dependent Variables

% Chloroform Emissions (per unit waste input)	Benzene Emission Rate (ug/min)	Benzene Emission Conc. (ug/dscm)	Benzene Emission Conc. (ug/dscm, corrected to 10% O2)
0.000005	720.00	34.33	49.24
0.000007	970.50	45.31	56.12
0.000007	240.00	10.99	12.35
0.000004	660.00	30.41	33.83

Independent Variables

R.T., Primary Chamber (s)	R.T., Secondary Chamber (s)	R.T., Both Chambers (s)	Flue Gas Flow Rate (dscfm)
NA	NA	4.7	3810
NA	NA	3.5	5040
NA	NA	3.5	5100
NA	NA	3.0	5960

Independent Variables

O2 Conc., Secondary Chamber Outlet (%)	O2 Conc. Stack (dry, %)	CO (ppm)	Cold THC (as propane, ppm)
NA	13.1	2	2
NA	12.4	23	2
NA	14.2	63	2
NA	13.5	120	2

APPENDIX F, cont

EMISSIONS ANALYSIS - INCIN.

Dependent Variables

% Benzene Emissions (per unit POHC input)	% Benzene Emissions (per unit waste input)	1,1,1-Trichloroethane Emission Rate (ug/min)	1,1,1-Trichloroethane Emission Conc. (ug/dscm)
0.00305	0.00011	38.00	1.81
0.00322	0.00013	21.98	1.03
0.00083	0.00003	22.00	1.01
0.00167	0.00009	26.00	1.20

Independent Variables

O2 Conc., Furnace Outlet (%)	O2 Conc., Boiler Outlet (%)	O2 Conc. Stack (dry, %)	CO (ppm)
NA	NA	12.4	4.3
NA	NA	13.0	0.9
NA	NA	13.2	1.2
NA	NA	15.6	<1

Independent Variables

Hot THC (ppm)	NOx (ppm)	Particulates (g/s)	Particulate Entering APCD (g/dscm)
NA	NA	NA	NA
NA	NA	NA	NA
NA	NA	NA	NA
NA	NA	NA	NA

EMISSIONS ANALYSIS - INCIN.

Dependent Variables

1,1,1-Trichloroethane Emission Conc. (ug/dscm, corrected to 10% O2)	% 1,1,1-Trichloroethane Emissions (per unit POHC input)	% 1,1,1-Trichloroethane Emissions (per unit waste input)	Tetrachloroethylene Emission Rate (ug/min)
2.60	0.000161	0.000006	42.00
1.27	0.000073	0.000003	42.75
1.13	0.000076	0.000003	20.50
1.33	0.000066	0.000003	22.00

Independent Variables

Cold THC (as propane, ppm)	Hot THC (ppm)	NOx (ppm)	Particulates (g/s)
2.5	NA	NA	0.1556
1.9	NA	NA	0.3500
1.7	NA	NA	0.1472
<1	NA	NA	0.1111

Independent Variables

APCD Efficiency (%)	ClPOHC Feed Rate (g/min)	HCl Stack Conc. (g/s)	Cl in Scrubber inlet (mg/l)
NA	168.7	NA	NA
NA	75.0	NA	NA
NA	115.4	NA	NA
NA	118.3	NA	NA

EMISSIONS ANALYSIS - INCIN.

Independent Variables

Tetrachloroethylene Emission Conc. (ug/dscm)	Tetrachloroethylene Emission Conc. (ug/dscm, corrected to 10% O2)	% Tetrachloroethylene Emissions (per unit POHC input)	% Tetrachloroethylene Emissions (per unit waste input)
2.00	2.87	0.000178	0.000006
2.00	2.47	0.000142	0.000006
0.94	1.05	0.000071	0.000003
1.01	1.13	0.000056	0.000003

Independent Variables

(average values, corrected to 3% O2)

Particulate Entering APCD (g/dscm, 7% O2)	APCD Efficiency (%)	ClPOHC Feed Rate (g/min)	HCl Stack Conc. (g/s)
0.17	NA	133	0.0375
0.29	NA	146	0.0447
0.11	NA	140	0.0697
0.10	NA	143	0.0272

Independent Variables

Cl in Scrubber outlet (mg/l)	Cl out/Cl in (scrubber)	Waste Load (Mbtu/hr)	Waste:Fuel Feed Ratios
NA	NA	9.0	NA
NA	NA	10.9	NA
NA	NA	8.8	NA
NA	NA	9.9	NA

APPENDIX F, cont.

EMISSIONS ANALYSIS - INCIN.

Independent Variables

T, Primary Chamber (°C)	T, Secondary Chamber (°C)	T, APCD (°C)	T, Stack (°C)
570	854	NA	663
720	867	NA	611
737	844	NA	646
689	904	NA	679

Independent Variables

Cl in Scrubber inlet (mg/l)	Cl in Scrubber outlet (mg/l)	Cl out/Cl in (scrubber)	Load (Mbtu/hr)
NA	NA	NA	9.9
NA	NA	NA	11.1
NA	NA	NA	12.1
NA	NA	NA	10.0

No. of POHCs
10
10
10
10

EMISSIONS ANALYSIS - INCIN.

Independent Variables

R.T., Primary Chamber (s)	R.T., Secondary Chamber (s)	R.T., Both Chambers (s)	Flue Gas Flow Rate dscfm
NA	0.069	NA	749.0
NA	0.067	NA	765.0
NA	0.066	NA	780.0
NA	0.063	NA	775.0

Independent Variables

Waste:Fuel Feed Ratios	No. of POHCs
15.2	13
9.1	13
4.2	13
6.4	14

APPENDIX F, cont

EMISSIONS ANALYSIS - INCIN.

Independent Variables

O2 Conc., Primary Chamber (%)	O2 Conc., Secondary Chamber (%)	O2 Conc. Stack (%)	CO (as propane, ppm)
NA	NA	13.3	1275.0
NA	NA	12.1	22.2
NA	NA	11.2	4.7
NA	NA	11.1	8.8

APPENDIX F, cont

EMISSIONS ANALYSIS - INCIN.

Independent Variables

(average values, corrected to 3% O_2)

Cold THC (ppm)	Hot THC (g/dscm)	NOx (ppm)	Particulates (g/sec)
71	NA	NA	0.01
1.9	NA	NA	0.01
<1	NA	NA	0.02
<1	NA	NA	0.01

APPENDIX F, cont

EMISSIONS ANALYSIS - INCIN.

Independent Variables

Particulate entering APCD (g/dscm)	APCD Efficiency (%)	Cl Feed Rate (g/min)	HCl Stack Conc. (g/sec)	Cl in Scrubber inlet (mg/L)
0.04	NA	17.67	0.28	NA
0.03	NA	12.35	0.18	NA
0.06	NA	2.26	0.35	NA
0.03	NA	6.70	0.42	NA

EMISSIONS ANALYSIS - INCIN.

Independent Variables

Cl in Scrubber outlet (mg/L)	Cl out/Cl in (scrubber)	Waste Load (Mbtu/hr)	Waste Load (lb/hr)	Waste:Fuel Feed Ratios
NA	NA	1.41	87	No fuel
NA	NA	1.62	101	No fuel
NA	NA	1.01	103	No fuel
NA	NA	0.67	102	No fuel

EMISSIONS ANALYSIS - INCIN.

No. of POHCs
3
3
3
3

APPENDIX G

EMISSIONS ANALYSIS - BOILERS

SITE D (ACUREX BOILER STUDY) [1]

Test No.	Total Emission Rate [2] (ug/min)	Total Emission Conc. (ug/dscm)	Total Emission Conc. (ug/dscm, corrected to 10% O2)	% Emissions (per unit fuel/waste input)	Total PIC Emission Rate (ug/min)
1	122856.0	217.2	152.8	0.00041	45972.0
2	367794.0	651.6	449.5	0.00100	298074.0
3	277212.0	505.4	350.9	0.00076	219042.0
4	525942.0	972.2	679.3	0.00137	458922.0
5	198294.0	494.2	361.5	0.00102	185154.0
6	189438.0	620.7	460.2	0.00099	130278.0
7	122868.0	325.3	236.4	0.00064	29910.0

[1] Arithmetic average of gas bag, VOST and MM5 data (blank corrected).

[2] Total organic emissions excluding C1 to C6 measurements.

[3] Toluene was a POHC in tests 4-7.

SITE E (ACUREX BOILER STUDY) [1]

Test No.	Total Emission Rate [2] (ug/min)	Total Emission Conc. (ug/dscm)	Total Emission Conc. (ug/dscm, corrected to 10% O2)	% Emissions (per unit fuel/waste input)	Total PIC Emission Rate (ug/min)
1	310500.0	843.3	537.5	0.0009	39600.0
2	338292.0	704.9	498.9	0.0008	296286.0
3	3436380.0	7029.1	5283.9	0.0112	3130200.0
4	363540.0	944.9	741.0	0.0012	183360.0
5	315480.0	600.6	477.8	0.0010	199980.0
6	360534.0	948.2	707.9	0.0015	219354.0
7	4121760.0	5546.6	4478.3	0.0096	2825400.0
8	1695864.0	3562.7	2641.8	0.0064	809304.0
9	1120740.0	2486.1	2007.3	0.0057	457320.0

[1] Arithmetic average of gas bag, VOST and MM5 data (blank corrected).

[2] Total organic emissions excluding C1 to C6 measurements.

[3] Toluene was a POHC in test no. 9.

EMISSIONS ANALYSIS - BOILERS

Dependent Variables

Total PIC Emission Conc. (ug/dscm)	Total PIC Emission Conc. (ug/dscm, corrected to 10% O2)	% PIC Emissions (per unit POHC input)	% PIC Emissions (per unit waste input)	Total ClPIC Emission Rate (ug/min)
81.3	57.2	NA	NA	28116.0
528.1	364.3	0.0064	0.0022	211008.0
399.3	277.2	0.0109	0.0016	158160.0
848.3	592.8	0.0390	0.0035	399564.0
461.5	337.6	0.0016	0.0019	184860.0
426.9	316.5	0.0012	0.0013	126192.0
79.2	57.5	0.0003	0.0003	19920.0

Dependent Variables

Total PIC Emission Conc. (ug/dscm)	Total PIC Emission Conc. (ug/dscm, corrected to 10% O2)	% PIC Emissions (per unit POHC input)	% PIC Emissions (per unit waste input)	Total ClPIC Emission Rate (ug/min)
107.6	68.6	NA	NA	39300.0
617.4	437.0	0.0740	0.0031	89820.0
6402.8	4813.1	0.1998	0.0270	3041400.0
476.6	373.7	0.0110	0.0013	47820.0
380.7	302.9	0.0107	0.0015	64380.0
576.9	430.7	0.0115	0.0016	74400.0
3802.1	3069.8	0.1442	0.0214	1888800.0
17[illegible].2	1260.7	0.0520	0.0060	482580.0
1014.5	819.1	0.0037	0.0037	397320.0

EMISSIONS ANALYSIS - BOILERS

Dependent Variables

Total CIPIC Emission Conc. (ug/dscm)	Total CIPIC Emission Conc. (ug/dscm, corrected to 10% O2)	% CIPIC Emissions (per unit CIPOHC input)	% CIPIC Emission (per unit ClWaste input)	PIC:POHC (***)	Bz Emission Rate (ug/min)
49.7	35.0	NA	NA	NA	10800.0
373.8	257.9	0.0045	0.0045	5.65	40800.0
288.3	200.2	0.0078	0.0078	5.79	34200.0
738.6	516.1	0.0340	0.0340	8.89	13200.0
460.7	337.0	0.0411	0.0411	385.74	BDL
413.5	306.6	0.0280	0.0280	3.00	3000.0
52.7	38.3	0.0044	0.0044	0.38	9000.0

Dependent Variables

Total CIPIC Emission Conc. (ug/dscm)	Total CIPIC Emission Conc. (ug/dscm, corrected to 10% O2)	% CIPIC Emissions (per unit CIPOHC input)	% CIPIC Emission (per unit ClWaste input)	PIC:POHC (***)	Bz Emission Rate (ug/min)
106.7	68.0	NA	NA	NA	BDL
187.2	132.5	NA	NA	22.44591	4560.0
6221.2	4676.6	0.2940	0.2940	11.96834	10800.0
124.3	97.5	0.0041	0.0041	2.096022	12000.0
122.6	97.5	0.0058	0.0058	7.061441	28800.0
195.7	146.1	0.0063	0.0063	4.080246	24600.0
2541.7	2052.2	0.1510	0.1510	32.5657	216000.0
1013.8	751.7	0.0488	0.0488	17.41113	54600.0
881.4	711.6	NA	NA	1.3783	60000.0

APPENDIX G, cont

EMISSIONS ANALYSIS - BOILERS

Bz Emission Conc. (ug/dscm)	Bz Emission Conc. (ug/dscm, corrected to 10% O2)	% Bz Emissions (per unit waste input)	% Bz Emissions (per unit fuel/waste input)	Toluene Emission Rate [4] (ug/min)
19.1	13.4	0.00E+00	3.57E-05	48000.0
72.3	49.9	3.05E-04	1.10E-04	45000.0
62.3	43.3	2.46E-04	9.37E-05	25800.0
24.4	17.0	1.01E-04	3.43E-05	44400.0
BDL	BDL	BDL	BDL	BDL
9.8	7.3	3.02E-05	1.57E-05	43200.0
23.8	17.3	8.82E-05	4.70E-05	78000.0

Bz Emission Conc. (ug/dscm)	Bz Emission Conc. (ug/dscm, corrected to 10% O2)	% Bz Emissions (per unit waste input)	% Bz Emissions (per unit fuel/waste input)	Toluene Emission Rate [3] (ug/min)
BDL	BDL	Undefined	BDL	204000.0
9.5	6.7	4.76E-05	1.38E-05	201000.0
22.1	16.6	9.31E-05	3.52E-05	78000.0
31.2	24.5	8.70E-05	3.84E-05	120000.0
54.8	43.6	2.17E-04	9.28E-05	106800.0
64.7	48.3	1.78E-04	1.05E-04	120000.0
290.7	234.7	1.64E-03	5.02E-04	720000.0
114.7	85.1	4.05E-04	2.06E-04	270000.0
133.1	107.5	4.91E-04	3.04E-04	324000.0

EMISSIONS ANALYSIS - BOILERS

Toluene Emission Conc. (ug/dscm)	Toluene Emission Conc. (ug/dscm, corrected to 10% O2)	% Toluene Emissions (per unit waste input)	% Toluene Emissions (per unit fuel/waste input)	DCM Emission Rate (ug/min)	DCM Emission Conc. (ug/dscm)
84.9	59.7	Undefined	1.59E-04	NA	NA
79.7	55.0	3.37E-04	1.22E-04	126000.0	223.2
47.0	32.7	1.86E-04	7.07E-05	96000.0	175.0
82.1	57.3	3.41E-04	1.15E-04	360000.0	665.5
BDL	BDL	BDL	BDL	108000.0	269.2
141.5	105.0	4.35E-04	2.26E-04	51600.0	169.1
206.5	150.1	7.64E-04	4.08E-04	BDL	BDL

Toluene Emission Conc. (ug/dscm)	Toluene Emission Conc. (ug/dscm, corrected to 10% O2)	% Toluene Emissions (per unit waste input)	% Toluene Emissions (per unit fuel/waste input)	CHCL3 Emission Rate (ug/min)	CHCL3 Emission Conc. (ug/dscm)
554.0	353.2	Undefined	5.95E-04	NA	NA
418.8	296.4	2.10E-03	6.07E-04	2040.0	4.3
159.5	119.9	6.73E-04	2.54E-04	BDL	BDL
311.9	244.6	8.70E-04	3.84E-04	2700.0	7.0
203.3	161.8	8.05E-04	3.44E-04	4380.0	8.3
315.6	235.6	8.67E-04	5.11E-04	12000.0	31.6
968.9	782.3	5.45E-03	1.67E-03	1260000.0	1695.6
567.2	420.6	2.00E-03	1.02E-03	348000.0	731.1
718.7	580.3	2.65E-03	1.64E-03	252000.0	559.0

APPENDIX G. cont

EMISSIONS ANALYSIS - BOILERS

Dependent Variables

DCM Emission Conc. (ug/dscm, corrected to 10% O2)	% DCM Emissions (per unit ClPOHC input)	% DCM Emissions (per unit Clwaste input)	1,1-DCE Emission Rate (ug/min)	1,1-DCE Emission Conc. (ug/dscm)
NA	NA	NA	NA	NA
154.0	0.0027	0.0027	21600.0	38.3
121.5	0.0048	0.0048	5520.0	10.1
465.0	0.0800	0.0800	21000.0	38.8
196.9	0.0240	0.0240	7800.0	19.4
125.4	0.0115	0.0115	6600.0	21.6
BDL	BDL	BDL	BDL	BDL

Dependent Variables

CHCL3 Emission Conc. (ug/dscm, corrected to 10% O2)	% CHCL3 Emissions (per unit ClPOHC input)	% CHCL3 Emissions (per unit Clwaste input)	PCE Emission Rate (ug/min)	PCE Emission Conc. (ug/dscm)
NA	NA	NA	NA	NA
3.0	NA	NA	66000.0	137.5
BDL	BDL	BDL	30000.0	61.4
5.5	0.0002	0.0002	37800.0	98.3
6.6	0.0004	0.0004	48000.0	91.4
23.6	0.0010	0.0010	52200.0	137.3
1369.0	0.1007	0.1007	570000.0	767.0
542.1	0.0352	0.0352	132000.0	277.3
451.3	NA	NA	120000.0	266.2

EMISSIONS ANALYSIS - BOILERS

Dependent Variables

1,1-DCE Emission Conc. (ug/dscm, corrected to 10% O2)	% 1,1-DCE Emissions (per unit CIPOHC input)	% 1,1-DCE Emissions (per unit Clwaste input)	T, Furnace (not measured, °C)	T, Boiler (°C)	T, APCD (°C)
NA	NA	NA	1400	NA	NA
26.4	0.0005	0.0005	1400	NA	NA
7.0	0.0003	0.0003	1400	NA	NA
27.1	0.0047	0.0047	1400	NA	NA
14.2	0.0017	0.0017	1400	NA	NA
16.0	0.0015	0.0015	1400	NA	NA
BDL	BDL	BDL	1400	NA	NA

Dependent Variables

PCE Emission Conc. (ug/dscm, corrected to 10% O2)	% PCE Emissions (per unit CIPOHC input)	% PCE Emissions (per unit Clwaste input)	T, Furnace (not measured, °C)	T, Boiler (°C)	T, Economizer (°C)
NA	NA	NA	1532	351	175
97.3	NA	NA	1539	352	160
46.1	0.0064	0.0064	1539	361	178
77.0	0.0026	0.0026	1539	377	177
72.7	0.0034	0.0034	1533	363	170
102.5	0.0041	0.0041	1509	319	148
619.3	0.0042	0.0042	1564	422	206
205.6	0.0576	0.0576	1536	359	165
214.9	NA	NA	1515	323	150

EMISSIONS ANALYSIS - BOILERS

Independent Variables

T, Stack (°C)	R.T., Furnace (s)	R.T., Boiler (s)	R.T., Total (s)	Flue Gas Flow Rate (dscfm)	O2 Conc., Furnace Outlet (%)
NA	1.1	NA	NA	20200	NA
NA	1.1	NA	NA	20160	NA
NA	1.1	NA	NA	19590	NA
NA	1.1	NA	NA	19320	NA
NA	1.3	NA	NA	14330	NA
NA	1.3	NA	NA	10900	NA
NA	1.3	NA	NA	13490	NA

Independent Variables

T, Stack (°C)	R.T., Furnace (s)	R.T., Boiler (s)	R.T., Total (s)	Flue Gas Flow Rate (dscfm)	O2 Conc., Furnace Outlet (%)
NA	0.7	NA	NA	13150	NA
NA	0.7	NA	NA	17140	NA
NA	0.7	NA	NA	17460	NA
NA	0.7	NA	NA	13740	NA
NA	0.7	NA	NA	18760	NA
NA	1.0	NA	NA	13580	NA
NA	0.5	NA	NA	26540	NA
NA	0.7	NA	NA	17000	NA
NA	1.1	NA	NA	16100	NA

APPENDIX G, cont

EMISSIONS ANALYSIS - BOILERS

Independent Variables		(average values, corrected to 3% O2)				
O2 Conc., Boiler Outlet (%)	O2 Conc. Stack (dry, %)	CO (ppm)	Cold THC (g/dscm)	Hot THC (g/dscm)	NOx (ppm)	Particulates (g/s)
3.7	5.4	75	NA	NA	240	0.63
3.5	5.1	118	NA	NA	250	1.76
4.2	5.2	88	NA	NA	242	1.11
4.0	5.3	107	NA	NA	231	1.07
3.8	6.0	107	NA	NA	203	0.24
4.4	6.2	100	NA	NA	202	0.26
5.0	5.9	127	NA	NA	193	0.27

Independent Variables		(average values, corrected to 3% O2)				
O2 Conc., Boiler Outlet (%)	O2 Conc. Stack (dry, %)	CO (ppm)	Cold THC (g/dscm)	Hot THC (g/dscm)	NOx (ppm)	Particulates (g/s)
3.0	3.8	87	NA	NA	278	0.304
3.9	5.5	97	NA	NA	378	0.323
4.4	6.4	135	NA	NA	431	0.408
6.0	7.0	129	NA	NA	439	0.336
5.9	7.2	138	NA	NA	413	0.332
4.9	6.3	115	NA	NA	446	0.245
6.0	7.4	134	NA	NA	359	1.01
4.6	6.2	83	NA	NA	492	0.091
5.3	7.4	106	NA	NA	164	0.223

EMISSIONS ANALYSIS - BOILERS

Independent Variables

Particulate Entering APCD (g/dscm)	APCD Efficiency (%)	ClPOHC Feed Rate (g/min)	HCl Stack Conc. (g/s)	Cl in Scrubber inlet (mg/l)	Cl in Scrubber outlet (mg/l)	Cl out/Cl in (scrubber)	Load (Mbtu/hr)
NA	NA	NA	0.21	NA	NA	NA	86.0
NA	NA	11.14	40.4	NA	NA	NA	94.9
NA	NA	11.56	23.5	NA	NA	NA	90.5
NA	NA	10.85	8.7	NA	NA	NA	88.0
NA	NA	10.26	5.7	NA	NA	NA	50.9
NA	NA	10.26	4	NA	NA	NA	48.7
NA	NA	10.53	4.9	NA	NA	NA	48.9

Independent Variables

Particulate Entering APCD (g/dscm)	APCD Efficiency (%)	ClPOHC Feed Rate (g/min)	HCl Stack Conc. (g/s)	Cl in Scrubber inlet (mg/l)	Cl in Scrubber outlet (mg/l)	Cl out/Cl in (scrubber)	Load (Mbtu/hr)
NA	NA	0	0.16	NA	NA	NA	72.3
NA	NA	0	0.095	NA	NA	NA	80.5
NA	NA	17.24	6.68	NA	NA	NA	68.9
NA	NA	19.28	6.51	NA	NA	NA	73.5
NA	NA	18.56	7.78	NA	NA	NA	70.0
NA	NA	19.67	11.115	NA	NA	NA	52.4
NA	NA	20.85	9.05	NA	NA	NA	107.0
NA	NA	16.48	8.61	NA	NA	NA	70.1
NA	NA	0	0.045	NA	NA	NA	58.6

APPENDIX G, cont

EMISSIONS ANALYSIS - BOILERS

Independent Variables

Waste:Fuel Feed Ratios	No. of POHCs (***)	C1 to C6 (GC Analysis, ppm)
0	0	5
0.54	1	11
0.58	1	19
0.48	1	32
0.95	2	42
0.97	2	25
1.03	2	14

Independent Variables

Waste:Fuel Feed Ratios	No. of POHCs (***)	C1 to C6 (GC Analysis, ppm)
0	0	36.6
0.4353	1	142.2
0.6705	4	90.8
0.6933	4	37.5
0.6983	4	143.5
1.2196	4	28.0
0.4042	4	24.0
0.0007	4	103.6
0.0012	2	56.1

EMISSIONS ANALYSIS - BOILERS

SITE F (ACUREX BOILER STUDY) [1]

Test No.	Total Emission Rate [2] (ug/min)	Total Emission Conc. (ug/dscm)	Total Emission Conc. (ug/dscm, corrected to 10% O2)	% Emissions (per unit fuel/waste input)	Total PIC Emission Rate (ug/min)
1	680886.0	2501.8	2217.0	0.0057	667656.0
2	526818.0	1847.9	1573.6	0.0044	453210.0
3	1086318.0	3777.3	3320.4	0.0087	1070916.0
4	100533.6	376.2	330.7	0.0009	74781.6

[1] Arithmetic average of gas bag, VOST and MM5 data (blank corrected).

[2] Total organic emissions excluding C1 to C6 measurements.

[3] Toluene was a POHC in this study.

SITE G (ACUREX BOILER STUDY) [1]

Test No.	Total Emission Rate [2] (ug/min)	Total Emission Conc. (ug/dscm)	Total Emission Conc. (ug/dscm, corrected to 10% O2)	% Emissions (per unit fuel/waste input)	Total PIC Emission Rate (ug/min)
1	4765557.0	36999.7	33057.1	0.03211	436425.0
2	457389.0	3798.9	3366.5	0.00307	414771.0
3	103749.0	861.7	769.9	0.00071	59049.0

[1] Arithmetic average of gas bag, VOST and MM5 data (blank corrected).

[2] Total organic emissions excluding C1 to C6 measurements.

EMISSIONS ANALYSIS - BOILERS

Dependent Variables

Total PIC Emission Conc. (ug/dscm)	Total PIC Emission Conc. (ug/dscm, corrected to 10% O2)	% PIC Emissions (per unit POHC input)	% PIC Emissions (per unit waste input)	Total CIPIC Emission Rate (ug/min)
2453.2	2174.0	NA	NA	584748.0
1589.7	1353.7	0.7167	0.0290	373650.0
3723.8	3273.3	0.5370	0.0541	1049784.0
279.9	246.0	0.0505	0.0044	56763.6

Dependent Variables

Total PIC Emission Conc. (ug/dscm)	Total PIC Emission Conc. (ug/dscm, corrected to 10% O2)	% PIC Emissions (per unit POHC input)	% PIC Emissions (per unit waste input)	Total CIPIC Emission Rate (ug/min)
3388.4	3027.3	0.0047	0.0029	436017.0
3444.9	3052.8	0.0044	0.0028	411855.0
490.4	438.2	0.0006	0.0004	52359.0

EMISSIONS ANALYSIS - BOILERS

Dependent Variables

Total CIPIC Emission Conc. (ug/dscm)	Total CIPIC Emission Conc. (ug/dscm, corrected to 10% O2)	% CIPIC Emissions (per unit CIPOHC input)	% CIPIC Emission (per unit ClWaste input)	PIC:POHC (***)	Toluene Emission Rate [3] (ug/min)
2148.5	1904.0	NA	NA	NA	7680.0
1310.6	1116.1	0.2784	0.2784	18.74318	14790.0
3650.3	3208.7	0.7200	0.7200	21.76659	6408.0
212.4	186.7	0.1130	0.1130	21.86596	2106.0

Dependent Variables

Total CIPIC Emission Conc. (ug/dscm)	Total CIPIC Emission Conc. (ug/dscm, corrected to 10% O2)	% CIPIC Emissions (per unit CIPOHC input)	% CIPIC Emission (per unit ClWaste input)	PIC:POHC (***)	CHCL3 Emission Rate (ug/min)
3385.2	3024.5	0.0047	0.0030	78.21237	360000.0
3420.7	3031.4	0.0044	0.0028	15.02793	138000.0
434.9	388.5	0.0006	0.0004	8.946818	16800.0

EMISSIONS ANALYSIS - BOILERS

Toluene Emission Conc. (ug/dscm)	Toluene Emission Conc. (ug/dscm, corrected to 10% O2)	% Toluene Emissions (per unit waste input)	% Toluene Emissions (per unit fuel/waste input)	DCM Emission Rate (ug/min)
28.2	25.0	Undefined	6.37E-05	NA
51.9	44.2	1.61E-03	2.13E-04	34800.0
22.3	19.6	3.67E-04	5.79E-05	594000.0
7.9	6.9	1.23E-04	1.79E-05	25200.0

CHCL3 Emission Conc. (ug/dscm)	CHCL3 Emission Conc. (ug/dscm, corrected to 10% O2)	% CHCL3 Emissions (per unit CIPOHC input)	% CHCL3 Emissions (per unit Clwaste input)	CLBZ Emission Rate (ug/min)
2795.0	2497.2	0.0039	0.0025	23400.0
1146.2	1015.7	0.0015	0.0009	8400.0
139.5	124.7	0.0002	0.0001	720.0

APPENDIX H, cont

EMISSIONS ANALYSIS - BOILERS

DCM Emission Conc. (ug/dscm)	DCM Emission Conc. (ug/dscm, corrected to 10% O2)	% DCM Emissions (per unit CIPOHC input)	% DCM Emissions (per unit Clwaste input)	BZ Emission Rate (ug/min)	BZ Emission Conc. (ug/dscm)
NA	NA	NA	NA	NA	NA
122.1	103.9	0.0259	0.0259	78000.0	273.6
2065.5	1815.6	0.4074	0.4074	15600.0	54.2
94.3	82.9	0.0502	0.0502	10800.0	40.4

CLBZ Emission Conc. (ug/dscm)	CLBZ Emission Conc. (ug/dscm, corrected to 10% O2)	% CLBZ Emissions (per unit CIPOHC input)	% CLBZ Emissions (per unit Clwaste input)	T, Furnace (not measured, °C)	T, Boiler (°C)
181.7	162.3	2.51E-04	1.60E-04	886	223
69.8	61.8	8.92E-05	5.72E-05	878	221
6.0	5.3	7.60E-06	4.97E-06	872	221

EMISSIONS ANALYSIS - BOILERS

Dependent Variables

BZ Emission Conc. (ug/dscm, corrected to 10% O2)	% BZ Emissions (per unit ClPOHC input)	% BZ Emissions (per unit Clwaste input)	T, Furnace (not measured, °C)	T, Boiler (°C)
NA	NA	NA	1370	NA
233.0	0.0581	0.0581	1370	NA
47.7	0.0107	0.0107	1370	NA
35.5	0.0215	0.0215	1370	NA

Dependent Variables

T, 1st Scrubber (°C)	T, Stack (°C)	R.T., Furnace (s)	R.T., Boiler (s)	R.T., Total (s)
63.5	30	0.4	NA	NA
61.9	28	0.4	NA	NA
61.8	28	0.4	NA	NA

APPENDIX H cont

EMISSIONS ANALYSIS - BOILERS

Dependent Variables

T, APCD (°C)	T, Stack (°C)	R.T., Furnace (s)	R.T., Boiler (s)	R.T., Total (s)	Flue Gas Flow Rate (dscfm)
NA	NA	2.0	NA	NA	9720
NA	NA	2.0	NA	NA	10182
NA	NA	2.0	NA	NA	10271
NA	NA	2.0	NA	NA	9543

Dependent Variables

Flue Gas Flow Rate (dscfm)	O2 Conc., Furnace Outlet (%)	O2 Conc., Boiler Outlet (%)	O2 Conc. Stack (dry, %)	CO (ppm)	Cold TUHC (ppm)
4600	NA	7.9	8.7	170	0.7
4300	NA	7.8	8.6	155	0.6
4300	NA	9.1	8.7	146	0.3

EMISSIONS ANALYSIS - BOILERS

Independent Variables

(average values, corrected to 3

O2 Conc., Furnace Outlet (%)	O2 Conc., Boiler Outlet (%)	O2 Conc. Stack (dry, %)	CO (ppm)	Cold TUHC (ppm)	Hot TUHC (ppm)
NA	NA	8.6	135	4.0	NA
NA	NA	8.1	139	1.5	NA
NA	NA	8.5	109	0.3	NA
NA	NA	8.5	NA	NA	NA

Independent Variables

Hot TUHC (ppm)	NOx (ppm)	Particulates (g/s)	Particulate Entering APCD (g/dscm)	APCD Efficiency (%)	CIPOHC Feed Rate (g/min)
NA	67	0.877	NA	NA	243.9
NA	67	1.79	NA	NA	244.7
NA	74	0.403	NA	NA	241.6

EMISSIONS ANALYSIS - BOILERS

Independent Variables

1% O2)

NOx (ppm)	Particulates (g/s)	Particulate Entering APCD (g/dscm)	APCD Efficiency (%)	ClPOHC Feed Rate (g/min)	HCl Stack Conc. (g/s)	Cl in Scrubber inlet (mg/l)
328	0.0807	NA	NA	NA	0.39	NA
275	0.363	NA	NA	2.24	0.97	NA
299	0.423	NA	NA	2.43	2.78	NA
243	0.438	NA	NA	0.84	4.85	NA

Independent Variables

(average values, corrected to 3% O2)

HCl Stack Conc. (g/s)	Cl in Scrubber inlet (mg/l)	Cl in Scrubber outlet (mg/l)	Cl out/Cl in (scrubber)	Load (Mbtu/hr)	Waste:Fuel Feed Ratios	No. of POHCs (***)
0.45	0.003	2.06	686.67	17.8	No fuel	2
0.43	0.0025	2.00	800.00	17.1	No fuel	2
0.49	0.003	2.14	713.33	17.9	No fuel	2

APPENDIX H, cont

EMISSIONS ANALYSIS - BOILERS

Independent Variables

Cl in Scrubber outlet (mg/l)	Cl out/Cl in (scrubber)	Load (Mbtu/hr)	Waste:Fuel Feed Ratios	No. of POHCs (***)	C1 to C6 (GC Analysis, ppm)
NA	NA	36.5	0	1	NA
NA	NA	35.5	0.1302	4	NA
NA	NA	35.7	0.1591	4	NA
NA	NA	32.6	0.1429	4	NA

C1 to C6 (GC Analysis, ppm)
16.0
7.2
11.0

APPENDIX I

EMISSIONS ANALYSIS - KILNS

SITE I (ACUREX KILN STUDY) [1]

Dependent Variables

Test No.	Total Emission Rate [1] (ug/min)	Total Emission Conc. (ug/dscm)	Total Emission Conc. (ug/dscm, corrected to 10% O2)	% Emissions (per unit fuel/waste input)	Total PIC Emission Rate (ug/min)
1	219024.0	353.9	714.5	0.001953	40866.0
2	594180.0	1015.3	2305.7	0.004675	8622.0
3	829020.0	1327.7	2953.5	0.006560	3078.0

[1] Arithmetic average of gas bag, VOST and MM5 data (not blank corrected).

[2] Total organic emissions (TUHC measurements not reported).

SITE II (ACUREX KILN STUDY) [1]

Dependent Variables

Test No.	Total Emission Rate [2] (ug/min)	Total Emission Conc. (ug/dscm)	Total Emission Conc. (ug/dscm, corrected to 10% O2)	% Emissions (per unit fuel/waste input)	Total PIC Emission Rate (ug/min)
1	18822.0	72.5	71.2	0.000090	12270.0
2	42331.8	232.6	196.5	0.000203	36558.0
3	54112.2	297.3	245.5	0.000325	37962.0
4	78744.0	426.1	346.6	0.000464	60114.0

[1] Arithmetic average of gas bag, VOST and MM5 data (not blank corrected).

[2] Total organic emissions (TUHC measurements not reported).

[3] Toluene was a POHC in this study.

GENERAL PORTLAND CEMENT KILN STUDY

Dependent Variables

Case	Total Emission Rate [2] (ug/min)	Total Emission Conc. (ug/dscm)	Total Emission Conc. (ug/dscm, corrected to 10% O2)	% Emissions (per unit fuel/waste input)	Total PIC Emission Rate (ug/min)
Baseline	2610000.0	1219.2	1549.7	NA	2240538.0
~1% Cl	2637091.8	1265.6	1555.8	NA	2248230.0
~4% Cl	21105305.7	10418.3	12548.0	NA	20703642.0

[1] Arithmetic average of VOST and MM5 data (not blank corrected).

[2] Total organic emissions excluding TUHC measurements.

EMISSIONS ANALYSIS - KILNS

Dependent Variables

Total PIC Emission Conc. (ug/dscm)	Total PIC Emission Conc. (ug/dscm, corrected to 10% O2)	% PIC Emissions (per unit POHC input)	% PIC Emissions (per unit waste input)	Total CIPIC Emission Rate (ug/min)
66.0	133.3	0.037440	0.000364	40404.0
14.7	33.5	0.007899	0.000068	7962.0
4.9	11.0	0.002820	0.000024	2766.0

Dependent Variables

Total PIC Emission Conc. (ug/dscm)	Total PIC Emission Conc. (ug/dscm, corrected to 10% O2)	% PIC Emissions (per unit POHC input)	% PIC Emissions (per unit waste input)	Total CIPIC Emission Rate (ug/min)
47.3	46.4	0.001172	0.000094	11838.0
200.9	169.7	0.003493	0.000344	34338.0
208.6	172.2	0.003627	0.000228	37428.0
325.3	264.6	0.005743	0.000354	59628.0

Dependent Variables

Total PIC Emission Conc. (ug/dscm)	Total PIC Emission Conc. (ug/dscm, corrected to 10% O2)	% PIC Emissions (per unit POHC input)	% PIC Emissions (per unit waste input)	Total CIPIC Emission Rate (ug/min)
1046.6	1330.4	NA	NA	61800.0
1079.0	1326.4	NA	NA	189420.0
10220.0	12309.2	NA	NA	132000.0

EMISSIONS ANALYSIS - KILNS

Dependent Variables

Total CIPIC Emission Conc. (ug/dscm)	Total CIPIC Emission Conc. (ug/dscm, corrected to 10% O2)	% CIPIC Emissions (per unit CIPOHC input)	% CIPIC Emission (per unit ClWaste input)	PIC:POHC Ratio	CCL4 Emission Rate (ug/min)
65.3	131.8	0.044496	0.044496	0.30	29640.0
13.6	30.9	0.009388	0.009388	0.28	1200.0
4.4	9.9	0.003351	0.003351	0.14	246.0

Dependent Variables

Total CIPIC Emission Conc. (ug/dscm)	Total CIPIC Emission Conc. (ug/dscm, corrected to 10% O2)	% CIPIC Emissions (per unit CIPOHC input)	% CIPIC Emission (per unit ClWaste input)	PIC:POHC Ratio	CH3CL Emission Rate (ug/min)
45.6	44.8	0.004216	0.004216	1.88	9360.0
188.7	159.4	0.012230	0.012230	9.33	32820.0
205.6	169.8	0.013331	0.013331	3.02	36000.0
322.7	262.5	0.021238	0.021238	4.50	58080.0

Dependent Variables

Total CIPIC Emission Conc. (ug/dscm)	Total CIPIC Emission Conc. (ug/dscm, corrected to 10% O2)	% CIPIC Emissions (per unit CIPOHC input)	% CIPIC Emission (per unit ClWaste input)	PIC:POHC Ratio	CHCL3 Emission Rate (ug/min)
28.9	36.7	NA	NA	6.08	6000.0
90.9	111.8	NA	NA	5.79	27420.0
65.2	78.5	NA	NA	51.82	132000.0

EMISSIONS ANALYSIS - KILNS

Dependent Variables

CCL4 Emission Conc. (ug/dscm)	CCL4 Emission Conc. (ug/dscm, corrected to 10% O2)	% CCL4 Emissions (per unit CIPOHC input)	% CCL4 Emissions (per unit Clwaste input)	C2H3CL Emission Rate (ug/min)
47.9	96.7	0.032273	0.032273	2640.0
2.1	4.7	0.001307	0.001307	1260.0
0.4	0.9	0.000268	0.000268	1080.0

Dependent Variables

CH3CL Emission Conc. (ug/dscm)	CH3CL Emission Conc. (ug/dscm, corrected to 10% O2)	% CH3CL Emissions (per unit CIPOHC input)	% CH3CL Emissions (per unit Clwaste input)	Toluene Emission Rate [3] (ug/min)
36.1	35.4	0.003334	0.003334	1278.0
180.3	152.4	0.011690	0.011690	1098.0
197.8	163.3	0.012822	0.012822	5718.0
314.3	255.7	0.020687	0.020687	6000.0

Dependent Variables

CHCL3 Emission Conc. (ug/dscm)	CHCL3 Emission Conc. (ug/dscm, corrected to 10% O2)	% CHCL3 Emissions (per unit CIPOHC input)	% CHCL3 Emissions (per unit Clwaste input)	BZ Emission Rate (ug/min)
2.8	3.6	NA	NA	2178000.0
13.2	16.2	NA	NA	2058000.0
65.2	78.5	NA	NA	20571000.0

EMISSIONS ANALYSIS - KILNS

Dependent Variables

C2H3CL Emission Conc. (ug/dscm)	C2H3CL Emission Conc. (ug/dscm, corrected to 10% O2)	% C2H3CL Emissions (per unit ClPOHC input)	% C2H3CL Emissions (per unit Clwaste input)	T, Furnace (not measured, °C)
4.3	8.6	0.002875	0.002875	590-650
2.2	4.9	0.001372	0.001372	590-650
1.7	3.8	0.001176	0.001176	590-650

Dependent Variables

Toluene Emission Conc. (ug/dscm)	Toluene Emission Conc. (ug/dscm, corrected to 10% O2)	% Toluene Emissions (per unit waste input)	% Toluene Emissions (per unit fuel/waste input)	Bz Emission Rate (ug/min)
4.9	4.8	0.000010	0.000006	2520.0
6.0	5.1	0.000010	0.000005	1560.0
31.4	25.9	0.000034	0.000034	2166.0
32.5	26.4	0.000035	0.000035	2106.0

Dependent Variables

BZ Emission Conc. (ug/dscm)	BZ Emission Conc. (ug/dscm, corrected to 10% O2)	% BZ Emissions (per unit ClPOHC input)	% BZ Emissions (per unit Clwaste input)	T, Furnace (not measured, °C)
1017.4	1293.2	NA	NA	NA
987.7	1214.2	NA	NA	NA
10154.5	12230.3	NA	NA	NA

EMISSIONS ANALYSIS - KILNS

Independent Variables

T, APCD (°C)	T, Stack (°C)	R.T., Kiln (s)	R.T., Total (s)	Flue Gas Flow Rate (dscfm)
NA	79	2.5	N/A	22100
NA	73	2.5	N/A	20900
NA	76	2.5	N/A	22300

Independent Variables

Bz Emission Conc. (ug/dscm)	Bz Emission Conc. (ug/dscm, corrected to 10% O2)	% Bz Emissions (per unit CIPOHC input)	% Bz Emissions (per unit Clwaste input)	C2H3CL Emission Rate (ug/min)
9.7	9.5	1.93E-05	1.21E-05	720.0
8.6	7.2	1.47E-05	7.48E-06	1122.0
11.9	9.8	1.30E-05	1.30E-05	840.0
11.4	9.3	1.24E-05	1.24E-05	780.0

Independent Variables

T, APCD (°C)	T, Stack (°C)	R.T., Kiln (s)	R.T., Total (s)	Flue Gas Flow Rate (dscfm)
NA	156	NA	NA	76458
NA	156	NA	NA	74417
NA	156	NA	NA	72350

APPENDIX I, cont.

EMISSIONS ANALYSIS - KILNS

Independent Variables
(average values, corrected to 3% O2)

O2 Conc., Kiln Outlet (%)	O2 Conc. Stack (dry, %)	CO (ppm)	Cold THC (g/dscm)	Hot THC (g/dscm)	NOx (ppm)	Particulates (g/s)
NA	15.5	N/A	N/A	N/A	66	0.0202
NA	16.1	50	N/A	N/A	57	0.0088
NA	16.0	57	N/A	N/A	56	0.0176

Independent Variables

C2H3CL Emission Conc. (ug/dscm)	C2H3CL Emission Conc. (ug/dscm, corrected to 10% O2)	% C2H3CL Emissions (per unit ClPOHC input)	% C2H3CL Emissions (per unit Clwaste input)	T, Furnace (not measured, °C)	T, APCD (°C)	T, Stack (°C)
2.8	2.7	0.0003	0.0003	1120-1180	NA	130
6.2	5.2	0.0004	0.0004	1120-1180	NA	123
4.6	3.8	0.0003	0.0003	1120-1180	NA	125
4.2	3.4	0.0003	0.0003	1120-1180	NA	123

Independent Variables
(average values, corrected to 3% O2)

O2 Conc., Kiln Outlet (%)	O2 Conc. Stack (dry, %)	CO (ppm)	Cold TUHC (ppm)	Hot TUHC (ppm)	NOx (ppm)	Particulates (g/s)
NA	12.3	212.0	10.2	NA	371.0	2.4792
NA	12.0	206.7	23.4	NA	347.7	2.2676
NA	11.9	165.0	17.4	NA	672.5	2.5736

EMISSIONS ANALYSIS - KILNS

Independent Variables

Particulate Entering APCD (g/dscm)	APCD Efficiency (%)	CIPOHC Feed Rate (g/min)	HCl Stack Conc. (g/s)	Cl in Scrubber inlet (mg/l)	Cl in Scrubber outlet (mg/l)	Cl out/Cl in (scrubber)
N/A	N/A	1.53	0.23	N/A	N/A	N/A
N/A	N/A	1.53	0.30	N/A	N/A	N/A
N/A	N/A	1.53	0.18	N/A	N/A	N/A

Independent Variables

					(average values, correc	
R.T., Kiln (s)	R.T., Total (s)	Flue Gas Flow Rate (dscfm)	O2 Conc., Kiln Outlet (%)	O2 Conc. Stack (dry, %)	CO (ppm)	Cold THC (g/dscm)
2.3	N/A	9270	NA	9.8	N/A	N/A
2.3	N/A	6500	NA	8.0	N/A	N/A
2.3	N/A	6500	NA	7.7	N/A	N/A
2.3	N/A	6600	NA	7.5	N/A	N/A

Independent Variables

Particulate Entering APCD (g/dscm)	APCD Efficiency (%)	CIPOHC Feed Rate (g/min)	HCl Stack Conc. (g/s)	Cl in Scrubber inlet (g/dscm)	Cl in Scrubber outlet (g/dscm)	Cl out/Cl in (scrubber)
NA	NA	NA	BDL	NA	NA	NA
NA	NA	NA	0.45	NA	NA	NA
NA	NA	NA	1.59	NA	NA	NA

EMISSIONS ANALYSIS - KILNS

Independent Variables

Load (Mbtu/hr)	Waste:Fuel Feed Ratios	No. of POHCs (***)	C1 to C6 (GC Analysis, ppm)
25.4	No fuel	8	NA
28.7	No fuel	8	NA
28.6	No fuel	8	NA

Independent Variables

ted to 3% O2)

Hot THC (g/dscm)	NOx (ppm)	Particulates (g/s)	Particulate Entering APCD (g/dscm)	APCD Efficiency (%)	ClPOHC Feed Rate (g/min)	HCl Stack Conc. (g/s)	Cl in Scrubber inlet (mg/l)
N/A	252	1.702	N/A	N/A	4.68	0.90	6
N/A	340	0.556	N/A	N/A	4.68	1.09	5
N/A	240	0.73	N/A	N/A	4.68	0.50	6
N/A	245	0.713	N/A	N/A	4.68	0.70	6

Independent Variables

Load (Mbtu/hr)	Waste:Fuel Feed Ratios	No. of POHCs (***)	C1 to C6 (GC Analysis, ppm)
158	NA	0	NA
169	NA	5	NA
143	NA	5	NA

EMISSIONS ANALYSIS - KILNS

Independent Variables

Cl in Scrubber outlet (mg/l)	Cl out/Cl in (scrubber)	Load (Mbtu/hr)	Waste:Fuel Feed Ratios	No. of POHCs (***)	C1 to C6 (GC Analysis, ppm)
540	534	N/A	1.6754	11	NA
400	395	N/A	1.0429	11	NA
610	604	29.0	No fuel	11	NA
650	644	29.7	No fuel	11	NA

APPENDIX J

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

EPA - IRF CHLORINATED BENZENES STUDY [1]

A. Stack Emissions

Dependent Variables

Test No.	Total Emission Rate [2] (ug/min)	Total Emission Conc. (ug/dscm)	Total Emission Conc. (ug/dscm, corrected to 10% O2)	% Emissions (per unit fuel/waste input)	Total PIC Emission Rate [3] (ug/min)
S1	120.2	6.89	5.60	0.000288	111.8
S2	224.7	12.88	10.47	0.000539	197.1
S3	253.1	16.11	16.11	0.000607	179.5
S4	265.8	16.92	16.92	0.000637	208.0
S5	191.4	13.88	15.28	0.000081	154.2
S6	185.4	13.45	14.80	0.000076	150.7
S7	197.7	14.64	14.64	0.000101	197.7
S8	269.7	18.35	18.35	0.000134	269.7
S9	139.6	8.07	6.33	0.000030	139.6
S10	116.9	7.00	5.70	0.000025	112.7
S11	155.3	10.71	25.37	0.000039	150.1
S12	212.0	13.21	10.36	0.000069	200.8
S13	155.7	9.21	7.22	0.000033	141.3
S14	243.8	14.43	11.73	0.000056	212.1
S15	321.5	20.09	16.34	0.000079	275.9
S16	156.6	8.42	NA	0.000031	156.6
S17	262.7	12.51	11.00	0.000048	262.7

[1] Arithmetic average of gas bag, VOST and MM5 data (blank corrected).

[2] Total organic emissions (TUHC measurements not reported).

[3] Only chlorinated organic emissions were measured.

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

Dependent Variables

Total PIC Emission Conc. (ug/dscm)	Total PIC Emission Conc. (ug/dscm, corrected to 10% O2)	% PIC Emissions (per unit POHC input)	% PIC Emissions (per unit waste input)	PIC:POHC Ratio
6.41	5.21	0.006708	0.000279	13.37
11.29	9.19	0.011824	0.000492	7.14
11.42	11.42	0.010768	0.000448	2.44
13.24	13.24	0.012479	0.000519	3.60
11.18	12.31	0.009251	0.000385	4.14
10.93	12.03	0.009044	0.000376	4.34
14.64	14.64	NA	NA	-
18.35	18.35	NA	NA	-
[illegible].07	6.33	NA	NA	-
6.75	5.49	0.006763	0.000282	26.71
10.35	24.54	0.009009	0.000376	29.33
12.51	9.81	0.002410	0.000558	17.93
8.36	6.56	0.001696	0.000392	9.81
12.55	10.21	0.001273	0.000683	6.69
17.24	14.03	0.001655	0.000889	6.05
8.42	NA	NA	NA	-
12.51	11.00	NA	NA	-

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

Dependent Variables

BZCL Emission Rate (ug/min)	BZCL Emission Conc. (ug/dscm)	BZCL Emission Conc. (ug/dscm, corrected to 10% O2)	% BZCL Emissions (per unit CIPOHC input)	1,3-DICLBZ Emission Rate (ug/min)
32.8	1.88	1.53	0.001968	41.6
31.3	1.79	1.46	0.001878	43.8
37.7	2.40	2.40	0.002262	45.3
56.7	3.61	3.61	0.003402	63.3
39	2.83	3.11	0.002340	48.9
44.5	3.23	3.55	0.002670	51.1
43.5	3.22	3.22	NA	47.8
52.1	3.54	3.54	NA	78.8
33.9	1.96	1.54	NA	52.9
38.7	2.32	1.89	0.002322	46.3
49	3.38	8.01	0.002940	60.2
54.4	3.39	2.66	0.000653	78.9
45.4	2.69	2.11	0.000545	45.8
35.6	2.11	1.71	0.000214	97.9
57.7	3.61	2.93	0.000346	107
38.7	2.08	NA	NA	50.1
69.6	3.31	2.91	NA	104

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

Dependent Variables

1,3-DICLBZ Emission Conc. (ug/dscm)	1,3-DICLBZ Emission Conc. (ug/dscm, corrected to 10% O2)	% 1,3-DICLBZ Emissions (per unit CIPOHC input)	T, Kiln (°C)	T, Afterburner (°C)
2.38	1.94	0.002496	871	1093
2.51	2.04	0.002628	871	1093
2.88	2.88	0.002718	760	982
4.03	4.03	0.003798	760	982
3.55	3.90	0.002934	700	877
3.71	4.08	0.003066	715	877
3.54	3.54	NA	643	877
5.36	5.36	NA	685	877
3.06	2.40	NA	871	1093
2.77	2.26	0.002778	871	1071
4.15	9.84	0.003612	871	1071
4.92	3.85	0.000947	871	1066
2.71	2.13	0.000550	871	1093
5.79	4.71	0.000587	871	1093
6.69	5.44	0.000642	871	1093
2.69	NA	NA	871	1093
4.95	4.35	NA	871	1093

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

Independent Variables

T, Stack (°C)	R.T., Kiln (s)	R.T., Afterburner (s)	R.T., Total (s)	Flue Gas Flowrate, Kiln (dscmm)
NA	NA	1.28	NA	NA
NA	NA	1.28	NA	NA
NA	NA	1.53	NA	10.28
NA	NA	1.53	NA	10.28
NA	NA	1.91	NA	5.35
NA	NA	1.91	NA	4.89
NA	NA	1.95	NA	7.00
NA	NA	1.79	NA	5.35
NA	NA	1.28	NA	7.90
NA	NA	1.35	NA	8.40
NA	NA	1.55	NA	8.04
NA	NA	1.41	NA	7.07
NA	NA	1.31	NA	6.80
NA	NA	1.31	NA	7.30
NA	NA	1.42	NA	7.30
NA	NA	1.19	NA	NA
NA	NA	1.05	NA	9.70

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

Independent Variables

Flue Gas Flowrate, Afterburner (dscmm)	O2 Conc., Kiln Outlet (%)	O2 Conc., Afterburner Outlet (%)	O2 Conc. Stack (dry, %)	CO, Kiln (ppm)
17.45	NA	7.50	NA	NA
17.45	NA	7.50	NA	NA
15.71	10.9	10.00	NA	NA
15.71	10.9	10.00	NA	NA
13.79	6.1	11.00	NA	NA
13.79	7.6	11.00	NA	NA
13.50	NA	10.00	NA	NA
14.70	NA	10.00	NA	NA
17.30	NA	7.00	NA	NA
16.70	NA	7.50	NA	NA
14.50	NA	16.30	NA	NA
16.05	NA	7.00	NA	NA
16.90	NA	7.00	NA	NA
16.90	NA	7.50	NA	NA
16.00	NA	7.50	NA	NA
18.60	NA	NA	NA	NA
21.00	NA	8.50	NA	NA

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

Independent Variables

CO, Afterburner (ppm)	Cold TUHC (ppm)	Hot TUHC (ppm)
0.0	NA	NA
0.0	NA	NA
0.0	NA	NA
0.0	NA	NA
0.0	NA	NA
0.0	NA	NA
0.0	NA	NA
0.0	NA	NA
0.0	NA	NA
0.0	NA	NA
0.0	NA	NA
0.0	NA	NA
0.0	NA	NA
0.0	NA	NA
0.0	NA	NA
0.0	NA	NA
0.0	NA	NA

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

Independent Variables

NOx (ppm)	Particulates (g/s)	Particulate Entering APCD (g/dscm)	APCD Efficiency (%)	ClPOHC Feed Rate (ug/min)
NA	NA	NA	NA	1666666.7
NA	NA	NA	NA	1666666.7
NA	NA	NA	NA	1666666.7
NA	NA	NA	NA	1666666.7
NA	NA	NA	NA	1666666.7
NA	NA	NA	NA	1666666.7
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	1666666.7
NA	NA	NA	NA	1666666.7
NA	NA	NA	NA	8333333.3
NA	NA	NA	NA	8333333.3
NA	NA	NA	NA	16666666.7
NA	NA	NA	NA	16666666.7
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

		Independent Variables		Independent Variables
HCl Stack Conc. (g/s)	Cl in Scrubber inlet (g/dscm)	Cl in Scrubber outlet (g/dscm)	Cl out/Cl in (scrubber)	Load (Mbtu/hr)
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

Independent Variables

Waste:Fuel Feed Ratios	No. of POHCs
No Fuel	1
No Fuel	1
No Fuel	1
No Fuel	1
0.2049	1
0.1995	1
0.0000	0
0.0000	0
0.1112	0
0.1497	1
0.0829	1
0.0930	1
0.0868	1
0.0851	1
0.0000	1
0.0000	0
0.0000	0

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

CRF CHLORINATED BENZENES STUDY CONT'D [1]

B. Afterburner Emissions

Dependent Variables

Test No.	Total Emission Rate [2] (ug/min)	Total Emission Conc. (ug/dscm)	Total Emission Conc. (ug/dscm, corrected to 10% O2)	% Emissions (per unit fuel/waste input)	Total PIC Emission Rate [3] (ug/min)
A19	10.2	0.64	0.54	NA	10.2
A21	10.1	0.58	NA	NA	10.1
A23	19.6	1.14	NA	NA	19.6
A25	0.3	0.02	0.01	NA	0.3
A27	0.2	0.01	0.01	NA	0.2
A29	0.1	0.01	NA	0.000000	0.1
A31	0.0	0.00	NA	0.000000	0.0
A33	0.1	0.00	0.01	NA	0.1
A35	0.0	0.00	0.00	NA	0.0
A37	0.8	0.06	0.06	NA	0.8
A39	0.1	0.01	0.01	NA	0.1
A41	33.8	2.22	1.68	0.000006	33.8
A43	30.7	2.02	1.53	0.000006	30.7
A47	17.8	1.02	0.83	0.000013	10.2
A49	4684.1	292.76	257.34	0.011246	4682.9
A51	4709.2	294.33	248.69	0.011307	4704.9
A61	134.0	9.28	8.15	0.000043	130.5
A63	9.9	0.73	0.73	NA	9.9
A65	26.1	1.92	2.01	NA	26.1
A67	26.9	1.98	2.11	0.000065	24.3
A69	10.2	0.74	0.86	0.000004	10.2
A71	4683.4	342.61	367.92	0.001903	4683.4

[1] Arithmetic average of gas bag, VOST and MM5 data (blank corrected).

[2] Total organic emissions (TUHC measurements not reported).

[3] Only chlorinated organic emissions were measured.

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

Dependent Variables

Total PIC Emission Conc. (ug/dscm)	Total PIC Emission Conc. (ug/dscm, corrected to 10% O2)	% PIC Emissions (per unit POHC input)	% PIC Emissions (per unit waste input)	PIC:POHC Ratio
0.64	0.54	NA	NA	-
0.58	NA	NA	NA	-
1.14	NA	NA	NA	-
0.02	0.01	NA	NA	-
0.01	0.01	NA	NA	-
0.01	NA	NA	NA	-
0.00	NA	NA	NA	-
0.00	0.01	NA	NA	-
0.00	0.00	NA	NA	-
0.06	0.06	NA	NA	-
0.01	0.01	NA	NA	-
2.22	1.68	0.002028	0.000085	-
2.02	1.53	0.001842	0.000077	-
0.58	0.47	0.000015	0.000015	1.34
292.68	257.28	0.280977	0.011712	3902.46
294.06	248.47	0.282295	0.011767	1094.17
9.03	7.94	0.007830	0.000326	36.97
0.73	0.73	NA	NA	-
1.92	2.01	NA	NA	-
1.79	1.91	0.001459	0.000061	9.39
0.74	0.86	NA	NA	-
342.61	367.92	NA	NA	-

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

Dependent Variables

BZCL Emission Rate (ug/min)	BZCL Emission Conc. (ug/dscm)	BZCL Emission Conc. (ug/dscm, corrected to 10% O2)	% BZCL Emissions (per unit ClPOHC input)	1,3-DICLBZ Emission Rate (ug/min)
<1.2	NA	NA	NA	<1.4
<1.2	NA	NA	NA	<1.4
<1.2	NA	NA	NA	1.94
<1.2	NA	NA	NA	<1.4
<1.2	NA	NA	NA	<1.4
<1.2	NA	NA	NA	<1.4
<1.2	NA	NA	NA	<1.4
<1.2	NA	NA	NA	<1.4
<1.2	NA	NA	NA	<1.4
<1.2	NA	NA	NA	<1.4
<1.2	NA	NA	NA	<1.4
21.3	1.40	1.06	0.001278	<1.4
19.5	1.28	0.97	0.001170	<1.4
<1.2	NA	NA	NA	<1.4
4680	292.50	257.12	0.280800	<1.4
4680	292.50	247.15	0.280800	<1.4
<1.2	NA	NA	NA	<1.4
<1.2	NA	NA	NA	<1.4
21.1	1.55	1.63	NA	<1.4
9.03	0.66	0.71	0.000542	<1.4
<1.2	NA	NA	NA	<1.4
4680	342.36	367.65	NA	<1.4

APPENDIX J, cont.

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

Dependent Variables

1,3-DICLBZ Emission Conc. (ug/dscm)	1,3-DICLBZ Emission Conc. (ug/dscm, corrected to 10% O2)	% 1,3-DICLBZ Emissions (per unit CIPOHC input)	T, Kiln (°C)	T, Afterburner (°C)
NA	NA	NA		1093
NA	NA	NA		1093
0.11	NA	NA		1093
NA	NA	NA		1093
NA	NA	NA		1093
NA	NA	NA		982
NA	NA	NA		982
NA	NA	NA		871
NA	NA	NA		871
NA	NA	NA		871
NA	NA	NA		871
NA	NA	NA		1093
NA	NA	NA		1093
NA	NA	NA		1093
NA	NA	NA		871
NA	NA	NA		871
NA	NA	NA		1027
NA	NA	NA		899
NA	NA	NA		899
NA	NA	NA		899
NA	NA	NA		815
NA	NA	NA		815

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

Independent Variables

T, Stack (°C)	R.T., Kiln (s)	R.T., Afterburner (s)	R.T., Total (s)	Flue Gas Flowrate, Kiln (dscmm)
NA	NA	1.38	NA	
NA	NA	1.28	NA	
NA	NA	1.28	NA	
NA	NA	1.34	NA	
NA	NA	1.33	NA	
NA	NA	1.47	NA	
NA	NA	1.57	NA	
NA	NA	1.76	NA	
NA	NA	2.13	NA	
NA	NA	1.81	NA	
NA	NA	1.93	NA	
NA	NA	1.45	NA	
NA	NA	1.45	NA	
NA	NA	1.27	NA	
NA	NA	1.65	NA	
NA	NA	1.65	NA	
NA	NA	2.16	NA	
NA	NA	2.32	NA	
NA	NA	2.25	NA	
NA	NA	2.3	NA	
NA	NA	2.4	NA	
NA	NA	2.35	NA	

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

Independent Variables

Flue Gas Flowrate, Afterburner (dscmm)	O2 Conc., Kiln Outlet (%)	O2 Conc., Afterburner Outlet (%)	O2 Conc. Stack (dry, %)	CO, Kiln (ppm)
16.00		8.00	NA	
17.20		NA	NA	
17.20		NA	NA	
16.50		7.50	NA	
15.40		8.25	NA	
16.35		NA	NA	
15.40		NA	NA	
15.00		11.25	NA	
12.40		10.50	NA	
14.60		10.50	NA	
13.70		11.00	NA	
15.20		6.50	NA	
15.20		6.50	NA	
17.43		7.50	NA	
16.00		8.50	NA	
16.00		8.00	NA	
14.45		8.50	NA	
13.60		10.00	NA	
13.60		10.50	NA	
13.60		10.70	NA	
13.67		11.50	NA	
13.67		10.75	NA	

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

Independent Variables

CO, Afterburner (ppm)	Cold TUHC (ppm)	Hot TUHC (ppm)
0.0	NA	NA
NA	NA	NA
NA	NA	NA
0.0	NA	NA
0.0	NA	NA
NA	NA	NA
NA	NA	NA
0.0	NA	NA
1.0	NA	NA
0.0	NA	NA
0.0	NA	NA
0.0	NA	NA
0.0	NA	NA
0.0	NA	NA
2.0	NA	NA
2.0	NA	NA
1.5	NA	NA
0.0	NA	NA
0.0	NA	NA
0.0	NA	NA
0.0	NA	NA
0.0	NA	NA

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

Independent Variables

NOx (ppm)	Particulates (g/s)	Particulate Entering APCD (g/dscm)	APCD Efficiency (%)	ClPOHC Feed Rate (ug/min)
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

Independent Variables

HCl Stack Conc. (g/s)	Cl in Scrubber inlet (g/dscm)	Cl in Scrubber outlet (g/dscm)	Cl out/Cl in (scrubber)	Load (Mbtu/hr)
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	
NA	NA	NA	NA	
NA	NA	NA	NA	
NA	NA	NA	NA	
NA	NA	NA	NA	

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

Independent Variables	
Waste Fuel Feed Ratios	No. of POHCs
NA	0
NA	0
NA	0
NA	0
NA	0
0.0000	0
0.0000	0
NA	0
NA	0
NA	0
NA	0
0.0833	0
0.0833	0
No Fuel	0
No Fuel	0
No Fuel	0
0.1488	0
	0
	0
	0
	0
	0

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

CRF CHLORINATED BENZENES STUDY CONT'D [1]

C. Kiln Emissions

Dependent Variables

Test No.	Total Emission Rate [2] (ug/min)	Total Emission Conc. (ug/dscm)	Total Emission Conc. (ug/dscm, corrected to 10% O2)	% Emissions (per unit fuel/waste input)	Total PIC Emission Rate [3] (ug/min)
K18	8.6	0.94	NA	NA	8.6
K20	61.9	8.42	NA	NA	61.9
K22	65.8	8.94	NA	NA	65.8
K24	0.1	0.01	NA	NA	0.1
K26	0.4	0.04	NA	NA	0.4
K28	0.6	0.05	NA	0.000000	9.6
K30	0.2	0.02	NA	0.000000	0.2
K32	0.1	0.02	0.02	NA	0.1
K34	0.1	0.01	0.01	NA	0.1
K36	1.7	0.22	NA	NA	1.7
K38	0.7	0.11	NA	NA	0.7
K40	49.6	6.61	NA	0.000010	48.6
K42	42.6	6.46	NA	0.000008	42.6
K44	436.2	76.53	NA	0.000327	226.2
K45	1396.0	222.29	NA	0.001047	714.0
K46	1903364.0	216291.37	NA	1.427523	1019364.0
K48	1461.5	152.24	131.18	0.003509	1314.5
K50	1150.8	119.87	114.61	0.002763	1116.1
K52	59.1	6.39	NA	0.000142	55.4
K53	16.9	1.83	NA	0.000041	13.6
K54	19.4	2.09	NA	0.000047	16.0
K55	10.9	1.42	1.18	0.000003	10.9
K56	4.9	0.64	0.53	0.000001	4.9
K57	5.6	0.73	0.63	0.000002	5.6
K58	21565.0	2516.34	3081.81	0.006947	10965.0
K59	20575.7	2400.90	2940.43	0.006628	10475.7
K60	7960.3	928.85	1137.58	0.002564	4050.3
K62	135.5	17.83	NA	NA	135.5
K64	102.4	13.48	NA	NA	102.4
K66	6448.5	848.49	NA	0.015483	3248.5
K68	33.1	3.90	4.16	0.000013	33.1
K70	1323.2	155.85	180.72	0.000538	1323.2
K72	1127.4	132.79	157.33	0.000392	1111.5

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

Dependent Variables

Total PIC Emission Conc. (ug/dscm)	Total PIC Emission Conc. (ug/dscm, corrected to 10% O2)	% PIC Emissions (per unit POHC input)	% PIC Emissions (per unit waste input)	PIC:POHC Ratio
0.94	NA	NA	NA	-
8.42	NA	NA	NA	-
8.94	NA	NA	NA	-
0.01	NA	NA	NA	-
0.04	NA	NA	NA	-
0.05	NA	NA	NA	-
0.02	NA	NA	NA	-
0.02	0.02	NA	NA	-
0.01	0.01	NA	NA	-
0.22	NA	NA	NA	-
0.11	NA	NA	NA	-
6.48	NA	0.002918	0.000122	49.83
6.46	NA	0.002557	0.000107	-
39.69	NA	0.000046	0.000339	1.08
113.69	NA	0.001071	0.001071	1.05
115836.82	NA	1.529046	1.529046	1.15
136.93	117.99	0.078871	0.003288	8.94
116.26	111.16	0.066965	0.002791	32.16
5.98	NA	0.003324	0.000139	14.85
1.47	NA	0.000817	0.000034	4.13
1.73	NA	0.000959	0.000040	4.69
1.42	1.18	NA	NA	-
0.64	0.53	NA	NA	-
0.73	0.63	NA	NA	-
1279.47	1566.99	0.657903	0.027424	1.03
1222.37	1497.06	0.628544	0.026200	1.04
472.61	578.82	0.243017	0.010130	1.04
17.83	NA	NA	NA	-
13.48	NA	NA	NA	-
427.44	NA	0.194913	0.008125	1.02
3.90	4.16	NA	NA	-
155.85	180.72	NA	NA	-
130.92	155.11	0.066692	0.002775	69.9072956

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

Dependent Variables

BZCL Emission Rate (ug/min)	BZCL Emission Conc. (ug/dscm)	BZCL Emission Conc. (ug/dscm, corrected to 10% O2)	% BZCL Emissions (per unit CIPOHC input)	1,3-DICLBZ Emission Rate (ug/min)
<0.67	NA	NA	NA	<0.77
<0.67	NA	NA	NA	46.8
<0.67	NA	NA	NA	50.2
<0.67	NA	NA	NA	<0.77
<0.67	NA	NA	NA	<0.77
<0.67	NA	NA	NA	<0.77
<0.67	NA	NA	NA	<0.77
<0.67	NA	NA	NA	<0.77
<0.67	NA	NA	NA	<0.77
<0.67	NA	NA	NA	<0.77
<0.67	NA	NA	NA	<0.77
38.8	5.17	NA	0.002328	0.735
39.3	5.95	NA	0.002358	0.142
<0.67	NA	NA	0.000029	<0.77
<0.67	NA	NA	NA	<0.77
<0.67	NA	NA	NA	<0.77
983	102.40	88.23	0.058980	10.3
1030	107.29	102.59	0.061800	4.55
1.29	0.14	NA	0.000077	<0.77
1.31	0.14	NA	0.000079	<0.77
1.33	0.14	NA	0.000080	<0.77
<0.67	NA	NA	NA	<0.77
2.51	0.33	0.27	NA	<0.77
1.03	0.13	0.12	NA	<0.77
126	14.70	18.01	0.007560	123
36.9	4.31	5.27	0.002214	129
3.92	0.46	0.56	0.000235	67.5
4.62	0.61	NA	NA	<0.77
<0.67	NA	NA	NA	<0.77
19.7	2.59	NA	0.001182	2.67
6.26	0.74	0.79	NA	<0.77
983	115.78	134.26	NA	10.3
1030	121.32	143.74	0.061800	<1.4

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

Dependent Variables

1,3-DICLBZ Emission Conc. (ug/dscm)	1,3-DICLBZ Emission Conc. (ug/dscm, corrected to 10% O2)	% 1,3-DICLBZ Emissions (per unit CIPOHC input)	T, Kiln (°C)	T, Afterburner (°C)
NA	NA	NA	871	
6.36	NA	NA	871	
6.82	NA	NA	871	
NA	NA	NA	871	
NA	NA	NA	871	
NA	NA	NA	760	
NA	NA	NA	760	
NA	NA	NA	760	
NA	NA	NA	760	
NA	NA	NA	760	
NA	NA	NA	760	
0.10	NA	0.000044	871	
0.02	NA	0.000009	871	
NA	NA	NA	774	
NA	NA	NA	718	
NA	NA	NA	763	
1.07	0.92	0.000618	760	
0.47	0.45	0.000273	760	
NA	NA	NA	760	
NA	NA	NA	760	
NA	NA	NA	760	
NA	NA	NA	760	
NA	NA	NA	760	
NA	NA	NA	760	
14.35	17.58	0.007380	538	
15.05	18.44	0.007740	538	
7.88	9.65	0.004050	538	
NA	NA	NA	538	
NA	NA	NA	538	
0.35	NA	0.000160	538	
NA	NA	NA	510	
1.21	1.41	NA	510	
NA	NA	NA	510	

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

Independent Variables

T, Stack (°C)	R.T., Kiln (s)	R.T., Afterburner (s)	R.T., Total (s)	Flue Gas Flowrate, Kiln (dscmm)
NA	NA		NA	9.15
NA	NA		NA	7.36
NA	NA		NA	7.36
NA	NA		NA	8.40
NA	NA		NA	8.75
NA	NA		NA	10.40
NA	NA		NA	8.90
NA	NA		NA	8.50
NA	NA		NA	7.00
NA	NA		NA	7.50
NA	NA		NA	6.60
NA	NA		NA	7.50
NA	NA		NA	6.60
NA	NA		NA	5.70
NA	NA		NA	6.28
NA	NA		NA	8.80
NA	NA		NA	9.60
NA	NA		NA	9.60
NA	NA		NA	9.26
NA	NA		NA	9.26
NA	NA		NA	9.26
NA	NA		NA	7.70
NA	NA		NA	7.70
NA	NA		NA	7.70
NA	NA		NA	8.57
NA	NA		NA	8.57
NA	NA		NA	8.57
NA	NA		NA	7.60
NA	NA		NA	7.60
NA	NA		NA	7.60
NA	NA		NA	8.49
NA	NA		NA	8.49
NA	NA		NA	8.49

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

Independent Variables

Flue Gas Flowrate, Afterburner (dscmm)	O2 Conc., Kiln Outlet (%)	O2 Conc., Afterburner Outlet (%)	O2 Conc. Stack (dry, %)	CO, Kiln (ppm)
	NA	NA	NA	NA
	NA		NA	NA
	NA		NA	NA
	NA		NA	NA
	NA		NA	NA
	NA		NA	NA
	NA		NA	NA
	8.75		NA	NA
	8.75		NA	NA
	NA		NA	NA
	NA		NA	NA
	NA		NA	NA
	NA		NA	NA
	NA		NA	NA
	NA		NA	2.3
	NA		NA	6
	8.25		NA	NA
	9.5		NA	NA
	NA		NA	NA
	NA		NA	NA
	NA		NA	NA
	7.75		NA	NA
	7.75		NA	NA
	8.25		NA	NA
	12		NA	20
	12		NA	10
	12		NA	3
	NA		NA	3
	NA		NA	2
	NA		NA	100
	10.7		NA	100
	11.5		NA	100
	11.7		NA	100

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

Independent Variables

CO, Afterburner (ppm)	Cold TUHC (ppm)	Hot TUHC (ppm)
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA
	NA	NA

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

Independent Variables

NOx (ppm)	Particulates (g/s)	Particulate Entering APCD (g/dscm)	APCD Efficiency (%)	CIPOHC Feed Rate (ug/min)
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	1666666.7
NA	NA	NA	NA	1666666.7
NA	NA	NA	NA	66666666.7
NA	NA	NA	NA	66666666.7
NA	NA	NA	NA	66666666.7
NA	NA	NA	NA	1666666.7
NA	NA	NA	NA	1666666.7
NA	NA	NA	NA	1666666.7
NA	NA	NA	NA	1666666.7
NA	NA	NA	NA	1666666.7
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	1666666.7
NA	NA	NA	NA	1666666.7
NA	NA	NA	NA	1666666.7
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	1666666.7
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	1666666.7

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

Independent Variables

HCl Stack Conc. (g/s)	Cl in Scrubber inlet (g/dscm)	Cl in Scrubber outlet (g/dscm)	Cl out/Cl in (scrubber)	Load (Mbtu/hr)
NA	NA	NA	NA	NA
NA	NA	NA	NA	
NA	NA	NA	NA	
NA	NA	NA	NA	
NA	NA	NA	NA	
NA	NA	NA	NA	
NA	NA	NA	NA	
NA	NA	NA	NA	
NA	NA	NA	NA	
NA	NA	NA	NA	
NA	NA	NA	NA	
NA	NA	NA	NA	
NA	NA	NA	NA	
NA	NA	NA	NA	
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	
NA	NA	NA	NA	
NA	NA	NA	NA	
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA
NA	NA	NA	NA	NA

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

Independent Variables	
Waste:Fuel Feed Ratios	No. of POHCs
0.0000	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	1
	1
	1
No Fuel	1
No Fuel	1
	1
	1
	1
No Fuel	1
No Fuel	1
No Fuel	0
0.0000	0
0.0000	0
0.0000	1
0.1488	1
0.1488	1
NA	0
NA	0
No Fuel	1
0.0000	0
0.0000	0
0.1627	1

APPENDIX I

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

EPA - IRF PCB STUDY [1]

Dependent Variables

Test No.	Total Emission Rate [2] (ug/min)	Total Emission Conc. (ug/dscm)	Total Emission Conc. (ug/dscm, corrected to 10% O2)	% Emissions (per unit fuel/waste input)	Total PIC Emission Rate (ug/min)
A. AFTERBURNER					
1	6807.26	321.70	294.67	0.000757	6797.52
3	5856.72	262.40	362.04	0.000642	5853.38
6	3046.35	163.69	180.23	0.000326	3044.88
B. STACK					
1	6435.60	304.14	278.58	0.000716	6426.93
3	11904.42	533.35	735.89	0.001305	11898.39
6	1390.35	74.71	82.26	0.000149	1386.07

[1] Arithmetic average of gas bag, VOST and MM5 data (blank corrected).

[2] Total organic emissions (TUHC not reported).

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

Dependent Variables

Total PIC Emission Conc. (ug/dscm)	Total PIC Emission Conc. (ug/dscm, corrected to 10% O2)	% PIC Emissions (per unit POHC input)	% PIC Emissions (per unit waste input)	Total CIPIC Emission Rate (ug/min)
321.24	294.25	0.000850	0.000850	5125.8830
262.25	361.84	0.000702	0.000702	5415.9034
163.62	180.14	0.000358	0.000358	2188.8152
303.73	278.21	0.000803	0.000803	6378.8936
533.08	735.52	0.001428	0.001428	4381.0142
74.48	82.00	0.000163	0.000163	881.7418

APPENDIX F, cont.

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

Dependent Variables				
Total CIPIC Emission Conc. (ug/dscm)	Total CIPIC Emission Conc. (ug/dscm, corrected to 10% O2)	% CIPIC Emissions (per unit CIPOHC input)	% CIPIC Emission (per unit ClWaste input)	PIC:POHC Ratio
242.2440	221.8874	0.000641	0.000641	698.4
242.6480	334.7928	0.000650	0.000650	1748.3
117.6150	129.4953	0.000258	0.000258	2071.1
301.4600	276.1272	0.000797	0.000797	740.8
196.2820	270.8195	0.000526	0.000526	1974.4
47.3800	52.1659	0.000104	0.000104	323.8

APPENDIX E, cont

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

Dependent Variables

CHCL3 Emission Rate (ug/min)	CHCL3 Emission Conc. (ug/dscm)	CHCL3 Emission Conc. (ug/dscm, corrected to 10% O2)	% CHCL3 Emissions (per unit ClPOHC input)	% CHCL3 Emissions (per unit Clwaste input)
90.30	21.0	19.24	0.000056	0.000056
124.70	29.0	40.01	0.000074	0.000074
43.00	10.0	11.01	0.000025	0.000025
193.50	45.0	41.22	0.000119	0.000119
43.00	10.0	13.80	0.000025	0.000025
34.40	8.0	8.81	0.000020	0.000020

APPENDIX E, cont.

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

Dependent Variables

C2HCL3 Emission Rate (ug/min)	C2HCL3 Emission Conc. (ug/dscm)	C2HCL3 Emission Conc. (ug/dscm, corrected to 10% O2)	% C2HCL3 Emissions (per unit ClPOHC input)	% C2HCL3 Emissions (per unit Clwaste input)
22.79	5.3	4.85	0.000014	0.000014
51.6	12	16.56	0.000030	0.000030
32.68	7.6	8.37	0.000019	0.00001[illegible]
55.9	13	11.91	0.000034	0.00003[illegible]
94.6	22	30.35	0.000056	0.00005
2.752	0.64	0.70	0.000002	0.000002

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

Independent Variables

T, Main Chamber (°C)	T, Afterburner (°C)	T, Quench Pot (°C)	T, Stack (°C)	R.T., Main Chamber (s)
1262	982	83	71	NA
1239	1012	82	67	NA
1267	1064	83	72	NA

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

Independent Variables

R.T., Total (s)	Flue Gas Flow Rate (dscmm)	O2 Conc., Afterburner (%, dry)
4.3	21.16	9.0
4.3	22.32	13.0
4.3	18.61	11.0

APPENDIX K, cont.

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

Independent Variables
(average values, corrected to 3% O2)

O2 Conc. Stack (dry, %)	CO (ppm)	Cold THC (g/dscm)	Hot THC (g/dscm)	NOx (ppm)
N/A	N/A	N/A	N/A	N/A
N/A	N/A	N/A	N/A	N/A
N/A	N/A	N/A	N/A	N/A

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

Independent Variables

Particulates (g/s)	Particulate Entering APCD (g/dscm)	CIPOHC Feed Rate (g/min)	HCI Stack Conc. (ppm)	Cl in Scrubber inlet (kg HCl/hr)
0.1175	N/A	480.0	6.5	24.4
0.0492	N/A	500.0	10.8	25.4
0.0778	N/A	510.0	12.2	22.8

APPENDIX K, cont.

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

Independent Variables

Cl in Scrubber outlet (kg HCl/hr)	Cl out/Cl in (scrubber)	APCD Efficiency (%)	Load (Mbtu/hr)	Waste:Fuel Feed Ratios	No. of POHCs
0.002	24.398	>99.99	1.8	8.09	1
0.002	25.398	>99.988	1.8	10.61	1
0.002	22.798	>99.99	1.8	10.08	1

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

EPA - IRF SYNTHETIC MIXTURE STUDY [1]

Dependent Variables

Test No.	Total Emission Rate [2] (ug/min)	Total Emission Conc. (ug/dscm)	Total Emission Conc. (ug/dscm, corrected to 10% O2)	% Emissions (per unit fuel/waste input)	Total PIC Emission Rate (ug/min)
A. Secondary Chamber Exit					
1	6223.8	811.80	1843.46	0.004914	6071.2
2	584.5	64.94	157.30	0.000408	496.8
3	5961.2	777.55	2492.73	0.005338	5942.4
4	173.1	19.97	27.91	0.000086	75.4
5	8179.6	962.30	1127.86	0.004719	7464.7
6	1582.7	193.80	1005.91	0.001337	1567.2
7	568.4	60.90	81.95	0.000264	324.8
8	3822.0	449.65	628.36	0.001911	3667.8
9	852.0	92.94	117.80	0.000373	848.8
10	1245.6	155.70	292.61	0.000821	1135.2
B. Scrubber Exit					
1	2140.2	147.60	699.50	0.001690	2140.2
2	232.8	25.40	62.92	0.000162	232.8
3	3784.9	445.28	1673.64	0.003389	3765.5
4	868.0	43.40	131.41	0.000430	840.0
5	4184.3	230.33	760.79	0.002414	4171.1
6	483.3	32.95	189.03	0.000408	473.7
7	823.5	58.13	121.85	0.000383	753.7
8	852.5	36.80	143.26	0.000426	746.0
9	2676.7	182.50	375.33	0.001172	2598.9
10	274.6	32.30	69.03	0.000181	274.6
C. Stack					
1	4406.6	303.90	1440.22	0.003479	4192.0
2	397.8	43.40	107.51	0.000278	397.8
3	782.9	92.10	346.17	0.000701	782.9
4	280.0	14.00	42.39	0.000139	

[1] Arithmetic average of gas bag, VOST and MM5 data (blank corrected).

[2] Total organic emissions excluding TUHC measurements.

APPENDIX L, cont

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

Dependent Variables

Total PIC Emission Conc. (ug/dscm)	Total PIC Emission Conc. (ug/dscm, corrected to 10% O2)	% PIC Emissions (per unit POHC input)	% PIC Emissions (per unit waste input)	Total CIPIC Emission Rate (ug/min)
791.90	1798.27	0.001212	0.001212	6039.0
55.20	133.71	0.000195	0.000195	478.8
775.10	2484.88	0.003358	0.003358	5924.8
8.70	12.16	0.000322	0.000322	70.2
878.20	1029.29	0.001999	0.001999	6172.7
191.90	996.05	0.000257	0.000257	1557.4
34.80	46.83	0.000486	0.000486	301.5
431.50	602.99	0.000292	0.000292	3659.3
92.60	117.37	0.001333	0.001333	835.1
141.90	266.67	0.000261	0.000261	1107.2
147.60	699.50	0.001212	0.001212	2050.3
25.40	62.92	0.000195	0.000195	141.2
443.00	1665.07	0.003341	0.003341	3713.7
42.00	127.17	0.000312	0.000312	260.0
229.60	758.38	0.001993	0.001993	3053.8
32.30	185.30	0.000252	0.000252	340.3
53.20	111.52	0.000445	0.000445	229.5
32.20	125.35	0.000255	0.000255	27.8
177.20	364.43	0.001294	0.001294	1982.9
32.30	69.03	0.000261	0.000261	146.2
289.10	1370.08	0.002375	0.002375	4109.3
43.40	107.51	0.000333	0.000333	372.2
92.10	346.17	0.000695	0.000695	612.0

APPENDIX L, cont

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

Dependent Variables

Total CIPIC Emission Conc. (ug/dscm)	Total CIPIC Emission Conc. (ug/dscm, corrected to 10% O2)	% CIPIC Emissions (per unit CIPOHC input)	% CIPIC Emission (per unit ClWaste input)	PIC:POHC Ratio
787.70	1788.74	0.022945	0.022945	39.79
53.20	128.86	0.001446	0.001446	5.67
772.80	2477.51	0.020666	0.020666	316.37
8.10	11.32	0.000213	0.000213	0.77
726.20	851.14	0.022351	0.022351	10.44
190.70	989.82	0.005272	0.005272	101.00
32.30	43.47	0.000958	0.000958	1.33
430.50	601.60	0.012107	0.012107	23.77
91.10	115.46	0.002359	0.002359	272.35
138.40	260.10	0.003961	0.003961	10.28
141.40	670.11	0.004119	0.004119	>189.2
15.40	38.15	0.000419	0.000419	>35.3
436.90	1642.14	0.011683	0.011683	194.30
13.00	39.36	0.000342	0.000342	30.00
168.10	555.24	0.005174	0.005174	314.52
23.20	133.09	0.000641	0.000641	49.69
16.20	33.96	0.000480	0.000480	10.79
1.20	4.67	0.000034	0.000034	7.00
135.20	278.05	0.003501	0.003501	33.43
17.20	36.76	0.000492	0.000492	>44.9
283.40	1343.07	0.008255	0.008255	19.53
40.60	100.58	0.001104	0.001104	NA
72.00	270.62	0.001925	0.001925	NA

APPENDIX L, cont

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

Dependent Variables

CH3CL Emission Rate (ug/min)	CH3CL Emission Conc. (ug/dscm)	CH3CL Emission Conc. (ug/dscm, corrected to 10% O2)	% CH3CL Emissions (per unit POHC input)	% CH3CL Emissions (per unit Waste input)
5750.0	750.00	1703.13	0.006161	0.006161
90.0	10.00	24.22	0.000077	0.000077
5903.3	770.00	2468.53	0.005807	0.005807
65.9	7.60	10.62	0.000056	0.000056
6120.0	720.00	843.87	0.006249	0.006249
1551.7	190.00	986.19	0.001481	0.001481
205.3	22.00	29.60	0.000184	0.000184
1530.0	180.00	251.54	0.001428	0.001428
815.8	89.00	112.80	0.000650	0.000650
776.0	97.00	182.29	0.000783	0.000783
406.0	28.00	132.70	0.000230	0.000230
9.2	1.00	2.48	0.000008	0.000008
27.2	3.20	12.03	0.000024	0.000024
220.0	11.00	33.31	0.000082	0.000082
2979.3	164.00	541.70	0.001423	0.001423
30.8	2.10	12.05	0.000016	0.000016
63.8	4.50	9.43	0.000038	0.000038
20.9	0.90	3.50	0.000007	0.000007
BDL	BDL	BDL	BDL	BDL
93.5	11.00	23.51	0.000089	0.000089
1740.0	120.00	568.70	0.000986	0.000986
5.5	0.60	1.49	0.000005	0.000005
45.1	5.30	19.92	0.000040	0.000040

APPENDIX L, cont.

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

Dependent Variables

Bz Emission Rate (ug/min)	Bz Emission Conc. (ug/dscm)	Bz Emission Conc. (ug/dscm, corrected to 10% O2)	% Bz Emissions (per unit POHC input)	% Bz Emissions (per unit Waste input)
32.2	4.20	9.54	0.000035	0.000035
18.0	2.00	4.84	0.000015	0.000015
17.6	2.30	7.37	0.000017	0.000017
5.2	0.60	0.84	0.000004	0.000004
850.0	100.00	117.20	0.000868	0.000868
9.8	1.20	6.23	0.000009	0.000009
23.3	2.50	3.36	0.000021	0.000021
8.5	1.00	1.40	0.000008	0.000008
13.8	1.50	1.90	0.000011	0.000011
8.8	1.10	2.07	0.000009	0.000009
89.9	6.20	29.38	0.000051	0.000051
64.2	7.00	17.34	0.000054	0.000054
51.9	6.10	22.93	0.000046	0.000046
200.0	10.00	30.28	0.000074	0.000074
1071.8	59.00	194.88	0.000512	0.000512
133.5	9.10	52.21	0.000071	0.000071
396.7	28.00	58.69	0.000234	0.000234
718.2	31.00	120.68	0.000246	0.000246
454.7	31.00	63.75	0.000226	0.000226
102.0	12.00	25.65	0.000097	0.000097
47.9	3.30	15.64	0.000027	0.000027
BDL	BDL	BDL	BDL	BDL
60.4	7.10	26.69	0.000054	0.000054

APPENDIX L, cont

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

Independent Variables

T, Primary Combustor Exit (°C)	T, Secondary Combustor Exit (°C)	T, Stack (°C)	R.T., Primary Combustor Chamber (s)	R.T., Total (s)
1030	440	NA	4.0	NA
1114	517	NA	4.0	NA
943	342	NA	4.0	NA
1274	664	NA	4.0	NA
1091	628	NA	4.0	NA
945	385	NA	4.0	NA
1310	782	NA	4.0	NA
1077	632	NA	4.0	NA
1175	793	NA	4.0	NA
1105	582	NA	4.0	NA

APPENDIX L, cont

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

Independent Variables

Flue Gas Flow Rate, Secondary Chamber Exit (dscmm)	Flue Gas Flow Rate, Stack (dscmm)	O2 Conc., Primary Combustor Exit (%)
7.67	14.50	2.3
9.00	9.17	3.3
7.67	8.50	5.6
8.67	20.00	1.3
8.50	18.17	5.1
8.17	14.67	8.2
9.33	14.17	4.5
8.50	23.17	9.2
9.17	14.67	8.0
8.00	8.50	4.7

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

Independent Variables

O2 Conc., Secondary Combustor Exit (%)	O2 Conc. Stack (dry, %)	CO, Primary Combustor Exit (ppm)	CO, Secondary Combustor Exit (ppm)	CO, Stack (ppm)
16.1	18.6	356	5	5
16.4	16.5	257	5	5
17.5	18.0	10	5	5
13.1	17.3	160	13	5
11.6	17.6	10	5	5
18.8	19.0	52	5	5
12.8	15.7	44	15	5
13.1	18.1	10	5	5
12.3	15.6	64	5	5
15.1	15.8	82	5	5

APPENDIX L, cont

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

Independent Variables

(average values, corrected to 3% O2)

TUHC, Primary Combustor Exit (ppm)	TUHC, Secondary Combustor Exit (ppm)	TUHC, Stack (ppm)	NOx, Primary Combustor Exit (ppm)	Particulates (mg/dscm @ 7% O2)
1	1	1	51	28
4	1	1	70	27
1	1	1	82	31
1	1	1	68	169
1	1	4.2	62	109
1	1	1	67	115
21	25	1	102	64
1	1	1	44	71
1	12	1	42	23
7	10	2	89	49

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

Independent Variables

Particulate Entering APCD (g/dscm)	APCD Efficiency (%)	CIPOHC Feed Rate (g/min)	HCl Stack Conc. (mg/dscm)	Cl in Scrubber inlet (mg/l)	Cl in Scrubber outlet (mg/l)	Cl out/Cl in (scrubber)
NA	NA	26.32	2.3	NA	NA	NA
NA	NA	28.00	0.7	NA	NA	NA
NA	NA	26.23	2.7	NA	NA	NA
NA	NA	27.07	2.4	NA	NA	NA
NA	NA	20.14	0.8	NA	NA	NA
NA	NA	25.96	0.7	NA	NA	NA
NA	NA	26.22	13.7	NA	NA	NA
NA	NA	24.55	0.8	NA	NA	NA
NA	NA	29.40	22.9	NA	NA	NA
NA	NA	28.03	5.3	NA	NA	NA

APPENDIX L, cont

EMISSIONS ANALYSIS - PILOT SCALE INCINERATORS

Independent Variables

Load (Mbtu/hr)	Waste:Fuel Feed Ratios	No. of POHCs
NA	2.8	4
NA	2.3	4
NA	10.2	4
NA	1.1	4
NA	1.0	4
NA	4.9	4
NA	0.7	4
NA	0.9	4
NA	0.9	4
NA	1.7	4